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SOME RECENT WORK ON PLANT VIRUSES

F. C. BAWDEN

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Nature of viruses.—The study of viruses and virus diseases is only forty or so years old but is already one of the major branches of pathology. The economic importance of virus diseases is difficult to exaggerate, for new ones are continually being discovered and few organisms seem to escape infection. They are probably at least as important as fungal diseases in plants and as bacterial diseases in animals. Viruses have continually excited great scientific interest because of their uncertain nature. They undoubtedly possess many properties characteristic of organisms; in particular, their powers of indefinite multiplication and of adaptation in susceptible hosts. Although workers in the past have often held conflicting views, there was little clear evidence contradicting the most widely held view that they were minute organisms, probably resembling small bacteria. Recently, however, the behaviour of viruses *in vitro* has been studied in greater detail, and this view has had to be considerably modified. Some viruses have been found to be amenable to the physical and chemical techniques used for the investigation of molecular substances, and as these methods are increasingly applied the properties of the virus particles are found to resemble those of protein molecules much more closely than those of organisms.

Despite the increase in the number of recognized virus diseases, and our knowledge of the nature of some viruses, it is still impossible to give either a positive definition of a virus or a single test to show conclusively that any given disease is a virus disease. Two essential properties characterize viruses and differentiate them from most other pathogens; their smaller size and their obligate parasitism. It is known from the results of filtration experiments using graded collodion membranes, and from determinations of the rates at which viruses sediment in a high-speed centrifuge, that different viruses have particles of different sizes. All are too small to be seen by ordinary microscopic methods, the largest having diameters of about 180 mμ and the smallest about 10 mμ. Filterability is less used as a criterion of a virus than it was, and by no means all the recognized virus diseases of plants have been shown to be caused by filter passers. The small virus-content of infective sap and absorption on to the filter prevent the filtration of some viruses, and difficulties of transmission prevent the testing of others. The only known method of transmitting some viruses, e.g. those causing Potato Paracrinkle and Tomato Big-bud, is by grafting, and it is obviously impossible to show that they pass filters. Transmission by grafting is a natural sequel to the ability of viruses to spread throughout the vegetative parts of plants and, coupled with the absence of a visible parasite, has almost become the test whether a plant disease shall be placed in the virus group or not.

Symptoms of virus diseases.—The behaviour of individual viruses

varies so greatly that it is difficult to make any generalizations to which there are no exceptions, but there are some features which are specific to virus diseases. Plants occasionally localize infection, and the virus of Tobacco Necrosis has no hosts in which it becomes systematic, but it is more usual for viruses to invade all the plant with the exception of the seeds. As a result, symptoms are scattered much more uniformly over the affected plants than they are in bacterial and fungal diseases. The viruses enter and are perpetuated in tubers, bulbs, runners, &c., and they are of greater economic importance and more difficult to control in plants propagated vegetatively than in those raised from seeds.

There are relatively few ways in which plants can show disease, and viruses with widely different properties *in vitro* may cause similar symptoms. The most common are mottling and deformation of the leaves, reduction in size and cropping power of the plant, and necrosis, which may be localized or general. As viruses appear to be obligate parasites their survival depends upon the continued existence of susceptible hosts, and it is unusual for them to kill infected plants. Some kill a few species, but they have alternative hosts in which they cause slight or no diseases. The same virus often causes quite different diseases in different plants, and symptoms are of little value in identifying viruses. Also, environmental conditions, especially temperature, greatly affect the symptoms; they may determine whether infection is localized or general, and whether the plant shows severe or no symptoms. The phenomenon of the carrier, an infected plant showing no abnormalities, is often encountered, especially in the potato, where the result of infection depends as much on the variety as on the virus used. In some potato varieties, viruses 'A', 'B', and 'X' are carried, but in others they produce mosiacs or lethal necroses, and it is quite common for grafts between apparently healthy individuals of different varieties to result in the death of both scion and stock, as each is carrying a virus lethal to the other.

Infection is often accompanied by characteristic histological changes, the most specific being the formation of intracellular inclusions. These may be either amorphous or crystalline and, although they are not found in all virus diseases, in some they are sufficiently frequent and common to be of diagnostic value. Mottled leaves usually show some hypoplasia or hyperplasia, and the chloroplasts are abnormal. A necrosis of the phloem is a common symptom, and in some diseases other tissues are also affected.

Vectors.—Few aspects of the subject are more interesting than the relationships of the viruses with their vectors, usually insects that feed by sucking rather than biting. In the field, insects are undoubtedly responsible for the spread of most viruses, and it is probable that many which now are known only to be transmitted by grafting or by mechanical inoculation do have vectors. However, some viruses have been extensively investigated and no vectors discovered. Oddly enough, some of these are the most stable viruses, e.g. the almost ubiquitous Tobacco Mosaic and Potato 'X', which occur in the plant in high concentration and are transmitted mechanically with great ease. It is probable that these are

spread in nature largely by the rubbing together of healthy and diseased plants, and by workers first handling infected and then healthy plants.

The viruses known to be insect-transmitted can be divided into two distinct types. The vectors of the first type are unable to infect a healthy plant immediately after feeding upon an infected one. After a so-called incubation period the vector becomes infective and then remains so for a long time, sometimes for the remainder of its life. The length of the incubation period varies considerably; for the Potato Leaf-roll virus in *Myzus persicae* it is 2 days, and for Aster Yellows virus in *Cicadula sexnotata* it is 10 days. The long periods for which the vectors remain infective has often been taken as evidence that viruses of this type multiply in them, but recent work on Curly Top of sugar-beet and Streak of maize suggest that this is not so. It has been found that the length of time the vectors remain infective depends directly upon the length of time they feed on the infected plant, and if they feed for only a few minutes they soon cease to be infective. This indicates that the virus acquired by feeding on infected plants is merely stored in the insect without any multiplication, and is ejected gradually on further feeding. For these vectors to become infective the virus must enter the blood-stream, and the ability of *Cicadulina mbila* to spread Streak of maize appears to be determined by the permeability of the gut wall.

With the exception of the virus of Tomato Spotted Wilt, the viruses of this type cannot be transmitted by mechanical inoculation methods. The reasons are still obscure. It used to be thought that they were stable only inside their hosts or vectors, being inactivated immediately in expressed sap, but recent work has shown some of them to be quite stable *in vitro*. For example, by feeding *Eutettix tenellus* artificially on expressed sap, Curly Top virus has been found to remain active for long periods, to resist drying, precipitation with alcohol, and other relatively drastic treatments. Also, the vector of Maize Streak can be infected by mechanical inoculation of infective sap although plants cannot. The vectors are all phloem-feeders and for infection to occur must remain feeding on a plant long enough to reach the phloem. It seems probable, therefore, that for infection to occur with viruses of this type they must be placed directly in the phloem.

The second type of insect-transmitted virus can also be transmitted by inoculation methods. Typical examples are Potato Virus 'Y', Cucumber Virus 1, and Hyoscyamus Virus 3, all of which are transmitted by aphides. These have quite different relationships with their vectors. The aphides can infect healthy plants immediately after feeding upon diseased ones; they cease to be infective after a few hours, and often a number of related species can act as vectors. These facts make it improbable that the viruses of this type have to enter the blood-stream of the insect before it becomes infective, and they have led many workers to suggest that the vectors act in a purely mechanical manner, their stylets merely behaving like needles and acquiring the virus as a contaminant. In spite of the transitory nature of the association of viruses of this type with their vectors, there is evidence that transmission is not merely mechanical. Firstly, the sap of plants infected with some of these viruses

has such a small virus-content that it is difficult to imagine the outside of aphides stylets adsorbing sufficient to give infections. Also, it would be expected that viruses occurring in the greatest concentration in plant sap, and which are most readily transmitted mechanically, such as Potato Virus 'X' and Tobacco Mosaic virus, would be most readily transmitted by aphides, but this is not so. Further, if the aphides were behaving purely mechanically it is difficult to see why all insects which feed similarly should not be efficient vectors, but the ability to transmit is usually restricted to a few related species.

Recent work on Hyoscyamus Virus 3 has given further evidence that transmission is not merely mechanical. The number of infections with this virus obtained by *Myzus persicae* varies inversely with the time the aphid feeds on the infected plants, and is greatest with feeding times of a few minutes. Also, the number is greater if the vector is starved for some hours before being fed on the infected plant. These facts are difficult to reconcile with the view that the virus is carried as a contaminant on the outside of the stylets, for there is no apparent reason why less virus should be adsorbed on to the mouth parts in 1 hour's than in 5 minutes' feeding, or why fasted aphides should adsorb more virus. On the other hand, if the virus is actually ingested by the vector the results can be explained by postulating something in them which reduces infectivity, the something being present in greater quantities in aphides which have recently fed than in those which have fasted.

Control.—Peach trees can be cured of some virus diseases by growing them for periods at relatively high temperatures, but there are no known methods of curing any other virus-infected plants. The problem of control, therefore, is largely one of preventing infection. This can be done by eliminating all sources of infection, e.g. by starting with clean stocks and 'rogueing' plants immediately they become infected, and by raising crops in conditions unsuitable for transmission. With diseases spread by insects this means either growing the crops in conditions unfavourable to the vectors or, where economically feasible, destroying them by spraying. The first method is conspicuously successful with the potato in the northern and western districts of the British Isles, where the high relative humidity and wind check aphid-movement and reduce virus-transmission to a minimum. With mechanically transmitted diseases, plants should be handled as little as possible, implements sterilized frequently, and contact between healthy and infected plants prevented. It used to be thought that viruses had limited host-ranges, but many are now known to infect large numbers of species often belonging to different genera or even families. Weeds should therefore be kept down, as these may be alternative hosts and act as sources of infection.

The ideal method of control would be the production of immune varieties, or of perfect carriers, but as yet this has had little success except in the sugar-cane. The production of varieties of tobacco which localize infection with mosiac viruses promises to be of economic importance, but as new virus strains appear to arise frequently, and immunity and carrying may be affected by changes in environmental conditions,

it is impossible to be sure for how long new varieties bred for resistance will retain this property.

It is now known that most viruses occur naturally in a number of variant strains, and this knowledge has suggested a possible method of reducing the losses at present caused by virus diseases. In general the different strains of a virus have similar chemical and physical properties, i.e. resistance to heating, ageing, pH changes, enzymes, &c., but they differ widely in the symptoms they cause. They may also differ slightly in their host ranges, in the ease with which they are transmitted, and in the readiness with which they invade infected plants. There is strong presumptive evidence that many viruses are continually mutating to give rise to new strains, but this cannot be proven for it is impossible to be sure that any given virus-source contains only one strain. The closest approximation to a single-spore culture of a fungus that can be obtained with a virus is a source derived from a single local lesion, but unfortunately there is no proof that a local lesion necessarily indicates infection with a single virus particle. The appearance of a new symptom in plants infected with virus derived from a single lesion strongly suggests that a new variant has arisen. On the other hand, it may merely indicate that the culture was a mixture, and that the relative proportions of the different strains have become altered. Some of the strains that have been isolated from single-lesion cultures have been found to be so difficult to transmit that it is difficult to believe they can have been accidentally carried over as contaminants through large numbers of transmissions, and these perhaps supply the strongest evidence for mutation.

Usually it is not difficult to determine if a plant is infected with a mixture of two or more unrelated viruses, for all the components are able to spread through infected plants and produce their characteristic effects. A mixture of strains of one virus, however, is much more difficult to detect, for the presence of one strain prevents another from becoming systemic and producing its characteristic symptoms. It is this inhibition of one strain by the presence of another that suggests the possibility of controlling virus diseases by a process of vaccination. Strains of a large number of economically important viruses are now known which produce few or no signs of disease in infected plants and probably have only a slight effect on cropping power. The symptomless plants fully infected with these masked strains are immune to other strains, and the serious diseases caused by the virulent ones can be largely obviated by deliberately infecting crops in their early stages with the masked strains. As a method of plant protection this is still in the experimental stage, and it is too early to say whether it will ever become practical, but scientifically it is of great interest as the first proved example of acquired immunity in plants.

The method so far has given encouraging results, but emphasis must be laid on the fact that it is accompanied by greater dangers than the vaccination of animals, which it superficially resembles. The exact mechanism of the acquired immunity is not known, but it is of the non-sterile type. Plants are immune to one strain only while they contain another in a fully active form, and there is no evidence for the production

of virus antibodies such as occurs in vaccinated animals. The immunity only extends to parts of the plants in which the masked strains have become fully established, and some days pass before the vaccinated plants are completely protected. If a plant is inoculated with two or more strains simultaneously they all enter and can be recovered, but the larger component of the mixture, or the strain which multiplies most rapidly, will tend to occupy most of the plant and obscure the effects of the others. As the strains have no mutual inactivating effect either *in vitro* or in the plant, it seems that the protection is due to the presence of one strain preventing the multiplication of another. This suggests that there may be only limited sites of multiplication, and that related strains multiply at the same sites and unrelated viruses at different ones. Viruses which produce no symptoms on some plants may produce severe diseases on others, and as there is also strong evidence that masked strains may mutate to give rise to virulent strains, it would seem to be a dangerous policy to distribute viruses widely as vaccines, even when they have been found to be avirulent experimentally. A further, and perhaps more serious, danger of the method is the possibility of the vaccinated plants becoming infected with another virus, for the protection is specific and limited to related strains of the vaccine. The result of a second infection is often much more serious than if the plant were infected with the second virus alone. Some of the most clearly defined diseases, e.g. Potato Crinkle and Tomato Streak, are now known to be the result of simultaneous infection with two different viruses, which together cause quite distinct and more severe symptoms than either causes alone. However, the specificity is useful experimentally, for it provides a convenient test for identifying unknown viruses. Infected plants have only to be re-inoculated with a series of known viruses until one is found to which they are immune, to identify the unknown virus as a strain of this.

Viruses as antigens.—Although there is no evidence that plant viruses produce antibodies in their hosts, they appear to be active antigens. The serum of animals injected with infected sap contains antibodies not found in animals injected with healthy sap. These antibodies specifically and quantitatively neutralize the infectivity of virus suspensions, and also form a visible precipitate with extracts of infected plants, but not with extracts of healthy plants. There is now a great deal of evidence indicating that the antigens specific to virus-infected plants are actually the viruses themselves, and serology is being increasingly used in both quantitative and qualitative work on plant viruses.

The precipitin test provides the most rapid test for the presence of a virus; in infectivity tests a period of days elapses before the inoculated plants show symptoms, whereas by testing with antiserum a specific reaction can be obtained in a few minutes. The results of serological tests, however, need checking with infectivity tests, for although the precipitin reaction is obtained only in the presence of virus, the virus need not necessarily be active. Inactivation of the virus by most methods does destroy the serological reactions, but virus inactivated by formalin, mild oxidation, nitrous acid, or by irradiation with X-rays and ultra-

violet light, appears to be antigenically unaltered. It still reacts with antiserum prepared against fully active virus, and when injected into animals produces antibodies identical with those produced with active virus. These findings have no immediate practical value with plant viruses, but if they are found to apply to animal viruses they may provide new methods of vaccination by the injection of inactivated virus.

As the strength of the precipitin reaction is directly proportional to the concentration of virus, it can be used for quantitative work and for comparing the virus-contents of different preparations. The method is especially valuable for viruses which do not produce easily countable local lesions, but even for those that do, it has the added advantages over the infectivity tests of rapidity and of eliminating the variations due to the differences in susceptibility of individual plants. The serological reactions are specific, e.g. sap from a plant infected with Tobacco Mosaic virus will react only with the sera from animals injected with this virus, and not with serum prepared against other viruses, and they can therefore be used for the rapid identification of viruses. The specificity is not exact, for one strain of a virus will react with serum prepared against another. In general, the virus strains which immunize plants against one another also react with each other's antisera. The detailed serological investigations that have been made recently have shown that related strains are very similar antigenically but not identical. Each virus is not a simple unit antigen but contains several different antigens, some being specific to individual strains but others are common to all.

Chemical nature and isolation.—The failure of viruses to grow *in vitro* suggested that techniques other than the usual bacteriological ones would be necessary for their isolation and examination. That they are closely associated with protein was suggested by the facts that they are active antigens and that some are inactivated by proteolytic enzymes. Other studies on their behaviour towards different physical and chemical treatments also supported this view, but it has become more and more evident that exact information on their nature could be obtained only by isolating them from infected tissues in quantities sufficient for detailed chemical investigations. With a number of viruses there is now good reason to believe that this view has been achieved.

Proteins that have not been found in healthy plants have now been isolated from plants infected with some viruses. These have been obtained in relatively large quantities and there is every reason to think they are the viruses themselves. The protein preparations are highly infective, about one-thousand-millionth of a gram being sufficient to infect a plant, and from plants infected with this amount more of the specific protein can be isolated. If it could be proved that the protein preparations were homogeneous it would of course follow that the proteins are the viruses. This, however, is impossible in practice, but investigations of a number of different kinds have failed to show any appreciable heterogeneity. The particular protein isolated from infected plants is determined solely by the infecting virus and is independent of the species of the host plant, e.g. the same protein can be isolated from tobacco and from phlox infected with Tobacco Mosaic virus, but a

different one can be isolated from tobacco infected with Potato Virus 'X'. From plants infected with different strains of the same virus, proteins with closely similar but not identical properties can be isolated. Isolations have now been made from a number of different hosts by various techniques and the material found to have similar analytical composition, infectivity, serological activity, and chemical and physical properties.

Specific proteins have now been isolated from plants infected with several strains of Tobacco Mosaic virus, Cucumber viruses 3 and 4, Potato Virus 'X', and Tomato Bushy Stunt virus. Although these viruses have widely different stabilities, all have been found to be nucleoproteins. The analytical composition of the first three is almost identical but the Bushy Stunt virus differs from them in having approximately twice their nucleic-acid content. No appreciable amounts of any substances other than nucleic acid and protein have been found in any of the highly purified preparations. Each protein has the stability and properties characteristic of the particular virus used, e.g. it has been known for some years that heating to 70° C. and incubation with trypsin, inactivates Potato Virus 'X' but not Tobacco Mosaic virus, and it has now been found that these treatments break down the proteins isolated from plants infected with Potato Virus 'X', but have no effect on those isolated from plants infected with Tobacco Mosaic virus. The amount of protein that can be isolated from infective sap is proportional to the infectivity and varies with the different viruses; with Tobacco Mosaic virus it can be as great as 3 grams per litre, whereas with Bushy Stunt virus it may be as little as 30 mg.

All the viruses that have yet been carefully purified have shown some properties characteristic of crystalline materials, but the degree of crystallinity varies, the preparations of Bushy Stunt virus being fully crystalline, and those of others liquid crystalline. This difference is probably due to the viruses having differently shaped particles, for whereas those of Bushy Stunt virus appear to be spherical the others are greatly elongated. Because they are rod-shaped particles they are easily orientated, and purified preparations of Tobacco Mosaic virus, Cucumber viruses 3 and 4, and Potato Virus 'X', show some interesting properties. Dilute solutions show strongly the phenomenon of anisotropy of flow, i.e. although invisible in polarized light when stationary they become visible when made to flow. When the solid content of solutions is sufficiently great the particles are spontaneously orientated and they then form liquid crystals, i.e. they become birefringent even when stationary. These three viruses behave very similarly in solution, but when precipitated with acid or strong salt solutions Potato Virus 'X' is quite amorphous, whereas Tobacco Mosaic virus and Cucumber viruses 3 and 4 form birefringent fibres.

Although Tobacco Mosaic virus forms only liquid crystals *in vitro*, it seems to form true crystals in the infected plants. It has been known for many years that cells contained flat crystalline plates in addition to the amorphous X-bodies, and there is now a great deal of evidence indicating that these crystals are rich in virus. As the acidity and salt-content

of cell sap are too small to precipitate the virus, it is improbable that the inclusions are deposits of pure virus, and it seems likely that they are insoluble complexes formed by the union of the virus with some host constituents. When the purified virus is mixed *in vitro* with certain proteins, protamines, and histones, it forms precipitates whose behaviour in many ways resembles that of the inclusions, and this fact may afford a clue to the nature of these characteristic bodies.

The difference in the crystalline state of the virus in the plant and *in vitro* may be a result of alterations in the size of the virus particles which appear to occur during purification. It seems that as produced in the plant the virus particles are relatively small but readily attach themselves end-to-end to form long rod-shaped aggregates. The tendency to form linear aggregates is greatly increased by precipitating the virus during purification, and the increase in size of the units is reflected in the greatly reduced filterability of the purified virus. The methods of purification are somewhat similar to those used for the isolation of enzymes. Much of the normal plant protein can be removed by heating infective sap to a temperature insufficient to inactivate the viruses, and the remainder is removed by repeatedly precipitating the viruses with acid and strong salt solutions, and by incubation with proteolytic enzymes which hydrolyse them but not the viruses. The size of none of the rod-shaped viruses is known at all accurately. The width of Tobacco Mosaic virus, determined by X-ray measurements, is approximately 17 mμ, but the length is unknown and probably varies within fairly wide limits. The size of the spherical particles of the Bushy Stunt virus does not appear to be altered significantly by the processes of purification and has been determined. They have a molecular weight of 8,800,000 and a diameter of 27·4 mμ. Although this is a good deal larger than most molecules, some non-pathogenic proteins, e.g. the haemocyanins, have greater molecular weights. As they have large molecular weights the viruses can easily be thrown out of neutral solutions by high-speed centrifuging, and this provides an alternative method of purification. The purity of preparations made solely by high-speed centrifuging is more doubtful, but the method does not appear to alter the physical properties of the rod-shaped viruses as much as the other methods do.

It is not the fact that the viruses form crystals or liquid crystals that separates them so definitely from organisms, for it is possible to imagine small organisms arranging themselves in space with a two or even a three-dimensional regularity. The real differences lie rather in the chemical simplicity of the viruses and in the regularity of their internal structure. All recognized organisms contain salts, sugars, and numerous substances other than protein, but the viruses seem to be simply solid masses of nucleoprotein containing no detectable amounts of either water or any diffusible substance. Also, the X-ray measurements show that the sub-units from which the virus particles are built up, are arranged in the same manner and with the same degree of regularity and complexity as in other well-defined proteins, such as feather keratin.

How far the results which have been obtained with these few viruses can be generally applied is not known. Tobacco Ringspot virus, Severe

Etch virus, and Hyoscyamus Virus 3 have been shown to be anisotropic, and are also presumably rod-shaped. They may also be similar chemically, but they have not yet been obtained in sufficient quantities or sufficiently pure for detailed investigations, The particles of these plant viruses are large when judged by molecular standards, but they are relatively small when compared with some of the known animal viruses. Filtration studies have shown some of these to have diameters up to 180 mμ, i.e. only just below the limit of visibility, and this size has been confirmed by means of photographs taken with ultra-violet light and microscopes of high resolving-power. Whether these large particles are also protein molecules, or aggregates of protein molecules, or whether they are organically more complex than the small plant viruses and contain substances in addition to protein and nucleic acid, still remains to be determined. It must also be left to future research to discover the means whereby the viruses multiply in their hosts. Since it has been found that some of them are nucleoproteins the suggestion has repeatedly been made that they are autocatalysts, reproducing like some proteolytic enzymes by the activation of precursors. Until such precursors for viruses have been found, however, it would be extremely premature to adopt this view.

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THE ROOT-SYSTEM OF *AGAVE SISALANA* IN CERTAIN EAST AFRICAN SOILS

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DURING 1937–8 a field investigation was made of the root-system of *Agave sisalana* in relation to some of the soil types on which it is grown in East Africa. Published references to the root-system of sisal are in the main confined to a few generalizations. The general view has been that the root-system is shallow and of small lateral extent, and that the plant grows well on a great variety of soils mainly of an alkaline nature [1, 2, 3, 4].

Technique.—As it was necessary to carry out this work with African assistants only, the 'water-method' of investigating root-systems, as described in detail by Nutman [5], was used. A sector of the root-system was excavated in the form of a triangular prism with apex at the base of the plant and base about 18 in. wide at a distance of 10 or more feet away. This was necessary to show, in the concentration that their importance warrants, the peripheral roots arising from the main roots in the sector. In each district investigated, at least two such sectors were made at right angles to each other in order to discover any variation in the radial distribution of the roots. As a check the whole root-system of several plants was excavated, and it was found that the sector method gave a reliable indication of the whole. The sector was prepared by digging a trench about 10–18 ft. long and 6–8 ft. deep, having one vertical face 1 ft. away from the base of the plant. The soil in this face was then washed away from the roots arising in the sector by means of water-jets provided by a powerful motor-driven pump. The pressure of water, controlled automatically, was varied between 40 and 100 lb., according to the nature of the soil. For the excavation of extremely fine roots very low pressures of water through nozzles of $\frac{1}{32}$ in. diameter were used. Hand excavation was resorted to if the water-method failed owing to the hardness of the soil. As the roots were exposed they were pegged in position on the vertical soil face. When the sector was completely exposed, all the roots from neighbouring plants and those from outside the sector of the plant under investigation were carefully removed by hand. With the aid of a string grid of 1 ft. squares the root-system was drawn to scale in the field.

After preliminary trials on plants of various ages, plants of the age group $4\frac{1}{2}$–$5\frac{1}{2}$ years were chosen as possessing root-systems that had attained their maximum development. In one area 20-year-old plants were investigated at the same time as others of $4\frac{1}{2}$–$5\frac{1}{2}$ years. These aged plants were of interest because they had poled much later than is usual in East Africa.

Plants were chosen as good specimens for their locality. They had all reached a height of at least 5 ft. above ground, except on certain poor soils (Nos. 2 and 6). The spacing was $2{\cdot}5 \times 1$ m., as is usual in

East Africa. They had all been cleaned once or twice annually by cutlassing the weeds between the rows. With the exception of the 20-year-old plants they had all been cut at least once and not more than twice. On one soil the bottom leaves had been removed during the process of cleaning the plants. This represented about one-third the normal first cut.

The figures that accompany the paper are on a uniform scale, each square representing one square foot of the vertical face of the sector. The point at which a root leaves the sector is marked by a small circle. The pH values for the soil reaction, as determined by the hydrogen-electrode method on a 1:2½::soil:water suspension of air-dried soils, are given at the side of the figures. In two soil samples the water-retaining capacity was determined at pF3 by the Schofield-Bouyoucos method as employed by Milne [6]. For convenience, the soils have been divided into 'acid' and 'alkaline' types. The latter are calcareous with one exception, which has the high pH of 9·15, due to traces of alkali bicarbonate. This, however, is not a true 'alkali' soil. In each description rainfall is given in terms of the extreme annual totals recorded during the life of the plants examined.

Certain terms used throughout this paper are explained below:

Bearers. Long, often well-branched main roots which extend radially from the base of the plant. They carry the feeders. They appear brown and shrivelled owing to the suberization of several layers of cells immediately outside the endodermis, with consequent degeneration of the tissues external to these layers. The bearers thus become, in the main, conducting strands only, except for a length of 6–18 in. behind the growing-points which is white and bears a number of root-hairs. Young bearers about 1–4 ft. long are often completely white, but they soon show the brown shrivelled appearance of the older bearers as suberization gradually extends outwards along their length. The bearers are usually about 2–4 mm. in diameter. They are rarely found below 4 ft. deep in the soil.

Feeders. Thin white roots of average diameter 1–2 mm. bearing numerous root-hairs. They arise as branches of the bearers. As they grow in length they gradually show suberization, which extends outward from the parent bearer.

Rhizomes. Creeping underground stems, varying greatly in thickness, which turn up at their ends to produce suckers. They are white and fleshy and bear brown scale leaves, together with a few feeding-roots.

Suckers. Young sisal plants developed vegetatively from the rhizomes. As soon as their leaves develop above ground they produce a small root-system corresponding to that of the parent plant.

Poling plants. Plants in which the large pole-like reproductive shoot is developed at the expense of the vegetative organs. It causes the end of leaf-production and results in the death of the plant. In East Africa the plants pole at widely varying ages, usually when they are between 5 and 10 years old, though it is not uncommon to find that in certain areas plants reach the age of 20 or more years before 'poling' takes place.

During the present investigation it was found that at the beginning of 'poling' there was no apparent difference between the root-systems of 'poling' and 'non-poling' plants: but as the poling shoot reached maturity the root-system showed progressive degeneration of the feeders. This degeneration is marked by the cessation of growth at the ends of the feeders and bearers, together with the shrivelling and gradual suberization of the white absorbing areas (see Fig. 2).

Acid Soils

Tanga Province

Soil (1), Figs. 1 and 2. Altitude *c.* 2,900 ft.

The soil is a laterized red loam developed on gneiss. The surface-layer of soil has a moderately high content of organic material and is of a light loamy texture to a depth of 3–6 in. The subsoil is a soft red clay-loam mixed with a few rotten rock fragments. Below 30 in. in depth it takes on a raw red colour and contains much rock brash. Drainage is good because the soil is always readily permeable to water. The soil reaction varies between pH 5·0 and pH 5·5.

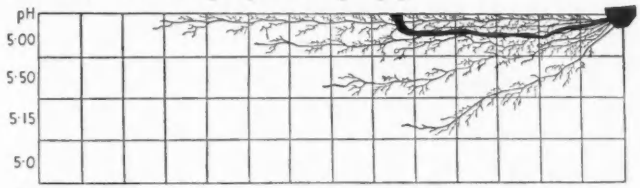

FIG. 1. Root-system of a 5-year-old unpoled plant in an acid loam soil.

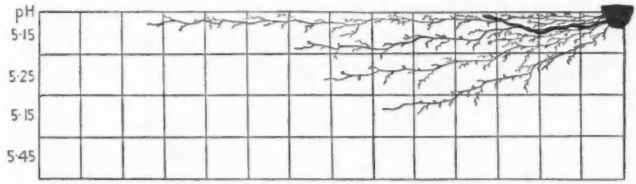

FIG. 2. Root-system of a 5-year-old poled plant in an acid loam soil.

The annual rainfall, which shows two well-marked maxima, had varied between 1,625 and 2,125 mm. It is well distributed throughout the year.

The root-systems of the six plants investigated penetrated the soil to a depth of 30–6 in., with the main concentration in the top 18 in. The lowest bearer reached a depth of 33 in. The bearers extended radially to a maximum of 10–14 ft. from the base of the plant. There were between 1 and 3 rhizomes in each sector.

Soil (2), Fig. 3. Altitude *c.* 1,000 ft.

The soil in the area investigated belongs to the group of non-calcareous black or grey clays of bottom lands (see East African Soil Map [7]). The ultimate parent rock is probably gneiss. The top 6 in. of the soil are drab black, stiff and cloddy, the next 6–12 in. of a deeper black with much smaller clods. Below 18 in. in depth the soil becomes yellowish due to an admixture of yellow-coloured aggregates, and then more sandy and friable with a noticeable platey structure. The fifth foot of the profile consists of a mottled, finely aggregated clay. Drainage is poor and there is a flowing water-table at this depth. The soil reaction varied between pH 5·2 and pH 6·2.

The local rainfall, which is well distributed but shows two maxima in the year, had varied between 875 and 1,725 mm.

The three plants investigated were about 4 ft. high and their leaves were not as well developed as those of plants in Soil (1). The root-systems also were only moderately well developed. Bearers were fewer and confined to the top 30 in. of soil, and they spread radially to a maximum distance of 9 ft. only. Living feeder-roots were found to a depth of 35 in. and a few dead ones a few inches lower. Rhizomes, averaging one in each sector, were poorly developed and very slender.

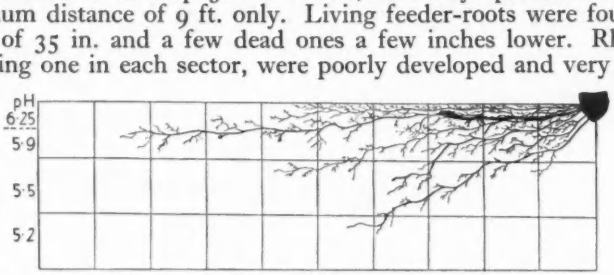

FIG. 3. Root-system of a 5-year-old plant in an acid clay soil.

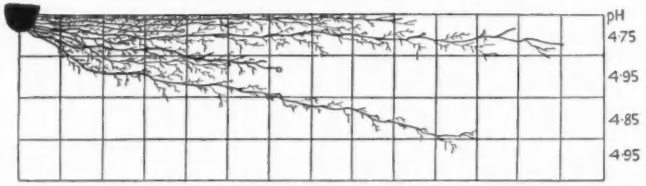

FIG. 4

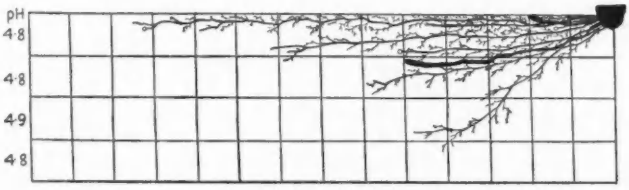

FIG. 5

FIGS. 4 and 5. Root-systems of 5-year-old plants in a coastal formation of acid, sandy clay soil.

Soil (3), Figs. 4, 5, and 6. Altitude *c.* 100 ft.

This soil overlies sandy coastal formations of the Tertiary or later age. It is a fairly open sandy clay of a friable laterized nature rather than a highly colloidal type. There is a marked washing down of the clay to the fourth foot in depth. The top-soil has not the marked darkening characteristic of soils of this type, and is probably accounted for by its low base-status. Drainage is good. All the sectors investigated were non-calcareous throughout, the soil reaction ranging from pH4·75 to pH5·4; in one area on which 20-year-old plants had been growing the top foot of soil had a value of pH7.

The annual rainfall in this area is well distributed throughout the year, but with two well-marked maxima. During the life of the four 5-year-old plants investigated it had varied between 1,000 and 1,500 mm.

The 5-year-old plants had a root-system similar to that found in Soil (1), with bearers extending to a depth of 30–6 in. and radially to a maximum of 10–15 ft. from the base of the plant. Feeders were found at a maximum depth of 40 in. The main concentration of roots was in the top 29 in. of soil. Rhizomes numbered 0–3 in each sector (Figs. 4, 5).

In the four 20-year-old plants investigated the bearers were confined to the top 18 in. of soil. They were few in number and bore few feeders, which were poorly developed and to a large extent suberized. Rhizomes numbered 1–4 in each sector (Fig. 6).

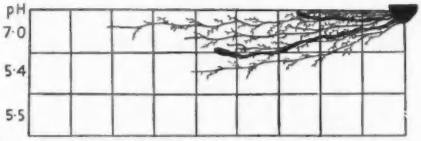

FIG. 6. Root-system of a 20-year-old plant in a coastal formation of acid, sandy clay soil.

Alkaline Soils

Tanga Province

Soil (4), Figs. 7 and 8. Altitude, sea-level.

The soil is a coarse, extremely well-drained, calcareous sand with a negligible amount of clay. The top foot of soil contains some organic matter which gives it a black appearance; below this there is very little organic matter and the soil is light brown. The soil reaction varied between pH8·4 and pH8·8. The water-retaining capacity of this soil was measured at pF3. It was found that the top foot of soil retained water to the extent of 10 per cent. of its dry weight, compared with only 5 per cent. in the second foot.

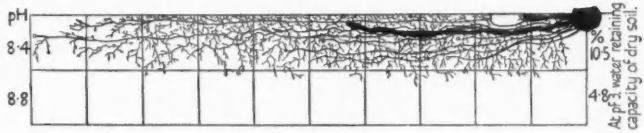

FIG. 7

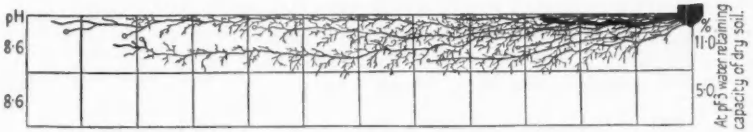

FIG. 8

FIGS. 7 and 8. Root-systems of 4½-year-old plants in coarse, coastal sand showing partition of the root-system between layers of different water-retaining capacities.

The annual rainfall in this area has two well-marked maxima and had varied between 1,000 and 1,400 mm. It is well distributed throughout the year.

The root-systems of the six plants investigated, both bearers and feeders, were confined to the top 12–14 in. of soil and formed a dense mat in this layer. A few dead feeders were found down to 24 in. The bearers extended radially to a maximum of 10–15 ft. from the base of the plant. Rhizomes, numbering 1–3 in each sector, were very thick and well developed.

Northern Province

Soil (5), Fig. 9. Altitude *c.* 2,500 ft.

The soil in this area is a fine volcanic alluvium, with no change in texture down to at least 7 ft. It contains no normal alkali carbonate, chloride, or sulphate, but a trace of alkali bicarbonate has raised the pH to 9·15. Drainage was good, although there was a water-table at a depth of 7 ft.

The annual rainfall in this area has two maxima. It is badly distributed throughout the year. During the life of the plants investigated it had varied between 530 and 1,500 mm.

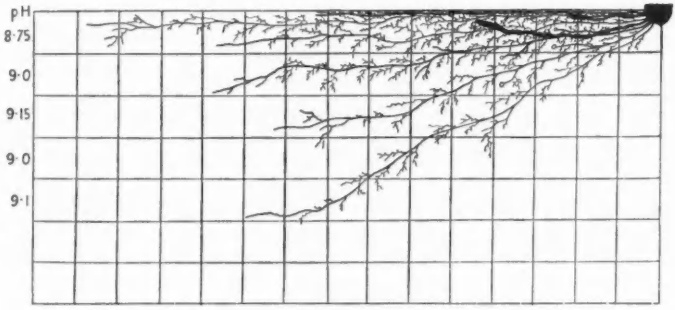

FIG. 9. Root-system of a 5½-year-old plant in an alkaline fine volcanic alluvium.

The root-systems of the four plants investigated were well distributed. The main concentration of the bearers and feeders occurred in the top two feet of soil, although a number of bearers were found down to a depth of 5 ft., and feeders were found to a depth of 5½ ft. The bearers spread radially to a maximum distance of 10–15 ft. from the base of the plant. In the layer between 5 and 6 ft. deep a number of dead feeders were found. Rhizomes numbered 1–3 in each sector.

Soil (6), Figs. 10 and 11.

At the same altitude and under the same annual rainfall as Soil (5), a different type occurs. This is a young volcanic soil in which leaching conditions favour the accumulation as carbonates of the bases formed in the weathering of the parent material. It is drab grey in colour, powdery, but more clayey at depth. It contained numerous hard calcareous fragments, alkali carbonate, and a little chloride, with a clayey panformation at a depth of 27 in. and rock at 5 ft. Drainage was poor because

of the pan- and rock-formations. The soil reactions of the sectors varied between pH 9·8 and pH 9·85.

Sisal in this soil is poorly developed for its age. Plants varied between 18 and 40 in. in height. Six plants of height 40 in. were examined. Their leaves, in common with those of other sisal plants in this area, were chlorotic.

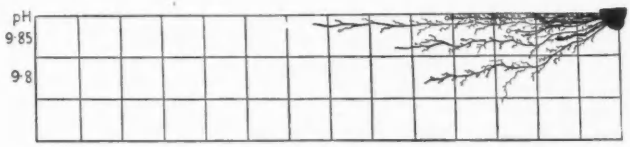

FIG. 10

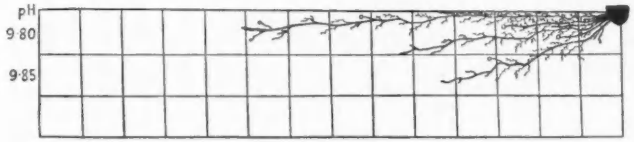

FIG. 11

FIGS. 10 and 11. Root-systems of 4½-year-old plants in a young volcanic soil of high alkalinity.

All the roots were found in the top 27 in. of soil. The bearers were few in number and extended radially to a maximum of 6–9 ft. from the base of the plant. Feeders, some of which penetrated the cracks in the hard pan to a depth of a few inches, were also few in number. The number of rhizomes varied from 1–4 in each sector. They were slender and poorly developed.

It is of interest to note that in this soil even the weed-growth is extremely poor.

Kenya. At the base of Kilimanjaro.
Soil (7), Fig. 12. Altitude *c.* 2,500 ft.

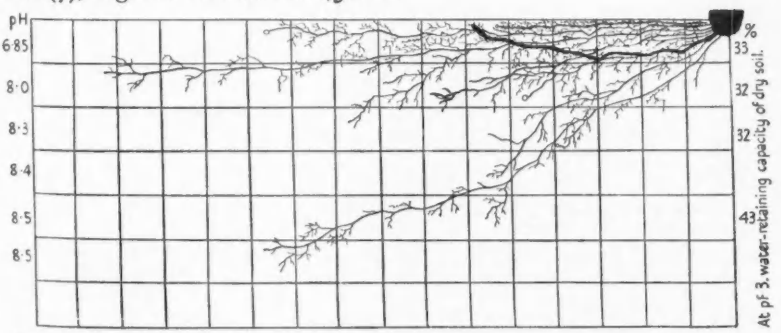

FIG. 12. Root-system of a 5-year-old plant in an alkaline, mature, loamy soil of high water-retaining capacity.

The soil in this area has been classed tentatively with the plains soils in the East African Soil Map [7], but it has been suggested by Milne [6] that this opinion may need revision on further investigation as the soil may possibly be derived from old lake-beds. It is a mature, loamy, crumb-structured, calcareous brown soil containing scattered traces of calcium carbonate below the top foot. It has a high base-exchange capacity and has many affinities with the ruling clay types of the temperate regions. The calcium carbonate present in the soil samples was not undesirably high, so the nutrient balance is not likely to be upset. Owing to the structure of the soil, drainage was good. The soil reactions of the profiles varied from pH6·85 in the top foot to pH8·5 in the fifth foot of soil. Measured at pF3 the water-retaining capacity of the soil proved to be 32–43 per cent. of its dry weight.

The annual rainfall in this area, which has two maxima, is badly distributed. It had varied between 400 and 1,000 mm. a year during the life of the plants investigated.

The root-systems of the six plants examined were deep and well distributed. Bearers, although mainly in the top 2 ft. of soil, were encountered to a depth of $5\frac{1}{2}$ ft. The maximum radial distribution of the bearers was 10–15 ft. from the base of the plant. Feeding roots, concentrated like the bearers mainly in the top 2 ft. of soil, were numerous, and were found to a depth of 75 in. Rhizomes numbered 0–3 in each sector.

Discussion

Conter [1] says that the roots of the sisal plant feed near the surface and do not descend to any great depth, in hard clay rarely more than 12 in., and in loose rocky soil seldom more than 18 in. He adds that, when given sufficient room, the roots will generally spread over an area equal to that covered by the mature leaves. Braun [2] states that the root-system of sisal is shallow, and that its spread is about $6\frac{1}{2}$ ft. in diameter; Tobler [3] that the root-system of the Agave is not wide spread, that roots of length over $4\frac{1}{2}$ ft. are very uncommon and that they do not penetrate deeply into the ground; Vageler [8] that Agaves have 'shallow spreading roots which are largely confined to the zone of soil between the surface and 30 in. in depth'. Such descriptions understate the size of the root-system of an average 5-year-old sisal plant in the soil types studied. In the present investigation it has been found that such a plant has many roots over 5 ft. in length, with a maximum radial spread of bearers to at least 10 ft. from its base. The main concentration of bearers and feeders is in the top 24 in. of soil, but both may be found to a depth of at least 40 in. and may even reach 6 ft.

It will be obvious that, under present East African planting practice, a spacing of $8 \times 3\frac{1}{4}$ ft. ($2{\cdot}5 \times 1$ m.) means that there is much root-competition between the rows and between plants in the same row. Lock [9] has in fact already shown experimentally that the growth of the sisal plant may be increased by wider spacing.

There is also very marked competition between the roots of the sisal and the roots of normal weeds (eliminated in Lock's experiment). In

the soils studied in this paper most of the weed roots occupied the same layers of soil as the sisal roots. The resulting competition is especially severe in areas liable to a deficiency of soil moisture. Lock [9] showed that if the soil is kept free from weeds, there is a marked increase in the growth-rate of the plant. Moreover, surface clean-weeding was more effective than clean-weeding combined with deep cultivation. There is no doubt that one effect of deep cultivation is to cut many of the important bearer roots which lie near the surface, so that the plants are deprived of a large part of their absorbing area.

The importance of the rainfall and the physical nature of the soil cannot be overestimated. Jack, Bishop, and Milsum [10] think rainfall is 'immaterial provided that where it is low (25–40. in), the soil is well cultivated and is capable of retaining a fair amount of moisture'. The view of Hindorf [11] is that in East Africa sisal grows well in almost any kind of soil and under average annual rainfalls from 600 to 1,500 mm. Since the effectiveness of the rainfall depends largely on the nature of the soil, these two factors cannot be considered separately. Two examples may be quoted from the present investigation. In the extremely coarse calcareous sandy soil (Figs. 7, 8), which has a well-distributed annual rainfall never less than 1,000 mm., the living root-system is confined to the top 12–14 in. of soil, whilst only a few dead roots are found below this depth. The top foot of this soil is capable of retaining water up to 10 per cent. of its dry weight at pF 3, the second foot only up to 5 per cent. Apparently the top foot of soil retains sufficient water to permit root-growth throughout the drier periods of the year. The presence of a few dead roots in the second foot of soil suggests that the roots grow into this layer only occasionally. On the other hand, in a calcareous loamy soil (Fig. 12) receiving a badly distributed annual rainfall of 400–1,000 mm., but capable of retaining water up to 43 per cent. of its dry weight, the root-system is well distributed to a depth of 6 ft. Apparently the sisal does not suffer from the extremely low rainfall because of the good water-holding capacity of the soil. The effectiveness of rainfall also depends on the proportion intercepted by the leaves of weeds growing between the rows and to some extent by the leaves of the sisal plants themselves. Clark [12] says that herbaceous vegetation intercepts at least 50 per cent. and 30 per cent. of rain falling at respective rates of $\frac{1}{8}$ in. and $\frac{1}{4}$ in. in the half-hour; but when the ground is cleaned, all rains, however light, can reach it [13].

The general opinion as to the best soil for the growth of the sisal plant is summed up by Dewey [4] as follows: 'Sisal grows well on a great variety of soils. It requires good drainage, a fair degree of fertility, and sufficient lime for an alkaline reaction.' The present investigation shows that the roots grow well on soils ranging from pH 9·15 to at least pH 4·75. The possibility that a high concentration of alkali upsets the nutrient balance of sisal is shown by Figs. 10 and 11, where the plant as a whole is poorly developed, its leaves chlorotic, and its root-system reduced in size. In East Africa the sisal plant has been grown for the most part on acid soils for many years, and there is no evidence that the yield of leaf or the strength and fineness of the fibre suffers in any way.

Conter [1], Dewey [4], Braun [2], and others have pointed out that the roots of sisal are extremely sensitive to water, and that sisal does not grow well on swampy soils. It is in fact so intolerant of such conditions that in certain soils (Figs. 3 and 9) the presence of a water-table causes the death of roots to a height of 12–18 in. above it.

Acknowledgements

I wish to record my thanks to the owners and managers of the various sisal estates who have provided material and labour for this investigation; to the Agricultural Officers who have assisted me with their specialized knowledge of the areas in which I worked; and to Mr. G. Milne, Soil Chemist at Amani, and Mr. W. E. Calton of the Amani Staff, who supplied the data on the pH and pF of the soil samples. I am also indebted to Mr. R. E. Moreau for his helpful criticism and advice with regard to meteorological and other data.

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PEAT SOILS AND PEAT-LAND RECLAMATION IN SWEDEN

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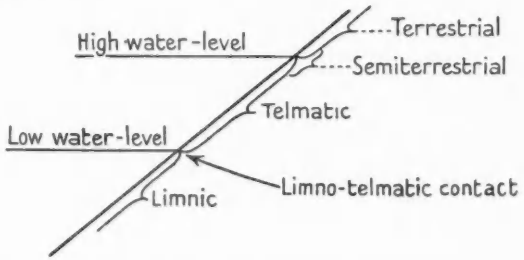
THE peat soils of Sweden occupy an area of 5·8 million hectares (14·3 m. acres), or 14·3 per cent. of the total land surface. The arable land occupies 3·7 m. ha. (9 m. acres). Owing to their great scientific and economic importance, these extensive peat areas have commanded much attention, and there is hardly any country where peat soils have been so well investigated as in Sweden. Lake-mud and similar soils formed below water-level are included in the term 'peat soils'.

Classification.—A purely morphological classification of peat soils has been used for some practical purposes, but having been found quite unsatisfactory, it has now been abandoned. For scientific work the nomenclature and classification of peat soils have always been based either on the genesis or on the botanical composition of the peat. The formation of peat can be regarded from the following points of view, which can also be used as a basis for classification:

1. The situation of the peat deposit in relation to the free-water surface, or to ground-water or precipitation, as follows: (*a*) limnic soils; (*b*) telmatic soils; (*c*) semiterrestrial soils; and (*d*) terrestrial soils, either soligenous, due to soil water, or ombrogenous, due to precipitation.



2. The method of deposition: (*a*) autochtonous or sedentary; (*b*) allochtonous or sedimentary.
3. Available plant-nutrients at the place of deposition: (*a*) eutrophic; (*b*) mesotrophic; (*c*) oligotrophic.
4. The mode of decomposition of the organic material: (*a*) mechanical; (*b*) microbiological and chemical.

The best system of classification is to use 1 for distinguishing the main groups, and 2, 3, and 4 for the subdivisions.

The nomenclature of those peat soils in which the predominant plant-material can easily be recognized is most conveniently based upon (1) the botanical composition of the peat, or (2) the parent plant-community, i.e. (i) *Sphagnum fuscum* peat, (ii) *Magnocaricetum* peat.

Since the properties of peat soils are determined by the plant-material in them and its stage of decomposition, this nomenclature involves morphological as well as genetical considerations. For example, *Sphagnum fuscum* peat means a peat consisting mainly of *Sphagnum fuscum*, but it also conveys that it has been formed from a plant-community dominated by *Sphagnum fuscum* in the bottom layer, and forming part of the vegetation of a bog. Even this modified genetic principle cannot, however, be applied consistently, and in some cases must be replaced by a morphological description.

The classification of peat entails a close examination of the remains of plants (and animals), and not merely of the more obvious ones; and of the structure (morphology) of the peat. Detailed examination facilitates reconstruction of the parent plant-community concerned, for secondary changes in undisturbed peat soils belonging to the late Quaternary period are usually inconsiderable. Accordingly, properties associated with degree of decomposition are mainly of primary origin. The most important properties are: (1) structure and colour; (2) content of sand, clay, precipitated lime and iron (especially in sedimentary deposits); (3) degree of decomposition, humification (expressed by von Post on a scale H = 1–10); (4) content of radicles, rhizomes, wood and bark, fruits and seeds; (5) wetness. Some inorganic precipitations, e.g. calcium and iron compounds, are classified with organic soils, partly because they occur in them, and partly because micro-organisms have taken part in their formation.

Classification of Organic Soils: Synopsis

I. Limnic Organic Soils
  A. Sediments
    Gyttia (mud, sapropel), clay-mud, chalk, diatomaceous mud, algal mud, &c.
  B. Sedentary soils (peat)
    Phragmites peat, *Equisetum* peat.

II. Telmatic Organic Soils (peat)
  A. Eutrophic (fen peat)
    Cladium peat, tall-sedge peat, *Amblystegium* peat.
  B. Oligotrophic (moss peat)
    Sphagnum cuspidatum peat, *Carex-Sphagnum* peat.

III. Semiterrestrial Organic Soils
  A. Eutrophic (fen peat)
    Dwarf peat, wood-fen (carr) peat.
  B. Oligotrophic (moss peat)
    Sphagnum fuscum peat, *Sphagnum magellanicum* peat, *Eriophorum vaginatum* peat.

IV. Chemical Sediments
    Lime-tuff (chalk), vivianite, limonite, siderite.

Peat resources of Sweden.—A quantitative survey of south Sweden has shown that the peat-lands occupy 8·3 per cent. of the total area, varying from 2 per cent. in the limestone regions to 16·9 per cent. in the granite

region of the south-west, where precipitation is high. In some counties 40 per cent. of the land is covered with peat.

Quantity and Depth of the Main Organogenic Soils of Sweden

	Quantity	*Depth*
	Million cub. m.	Metres
Sphagnum peat . . .	13,100	1·13 (52·3%)
Wood peat	4,800	0·41 (19·0%)
Sedge and reed peat . .	3,900	0·33 (15·3%)
Muds	3,400	0·29 (13·4%)
	Total 25,200	2·16 (100%)

Peat suitable for fuel was estimated at 12,000 million cub. m. and peat for litter at 4,300 millions.

Properties of practical importance.—Peat soils differ in several ways from mineral soils; for example, the average weight per cubic metre of mineral soils is 1,250–1,500 kg., that of mud soils is 375 kg., fen soils 250 kg., and moss soils 150 kg. Further, peat soils are often subject to considerable contraction in volume (due to shrinkage after draining), to decomposition of organic matter, and to wind-erosion. Consequently, the surface of cultivated peat soils sometimes sinks as much as 1 cm. a year, so necessitating the periodic deepening of ditches. To ensure successful reclamation it is therefore desirable that the peat soils should possess a certain depth, and further, that the mineral subsoil should be cultivable. After draining, some peat soils become pulverized, so diminishing their capacity for absorption. Low conductivity and capacity for heat are characteristic of peat soils; consequently they warm up slowly in spring and cool gradually in autumn, although the temperature of the top soil may fall appreciably during a cold night and expose plants to the risk of damage by frost.

As a rule peat soils possess great water-holding capacity. Part of the water is, however, held so firmly that it is not available to plants, and on some soils these may wilt at a moisture-content of 60 per cent.

The amount of available plant-nutrients in peat soils varies widely. The nitrogen-content ranges from 3 per cent. in certain sedge peats to less than 0·5 per cent. in poor moss peats. Still greater variations are found in the lime-content, which may rise to 10 per cent., corresponding to 75,000–100,000 kg. lime per hectare in the plough-layer, or fall to about 1,000 kg. of lime per hectare.

The soil reaction varies as a rule with the lime-content. Lime-deficient moss peat, for instance, is always strongly acid, with pH values round about 3·5, whilst calcareous fen soils sometimes are neutral. Most peat soils are very low in potash and phosphate. Sulphuric acid is sometimes found in concentrations high enough to be injurious to plant life.

Reclamation of peat-lands.—Peat-lands can be divided into two main groups: fen peat formed under the influence of, and moss peat developed independently of, the ground-water. The most important condition for the successful reclamation of peat-land is that drainage can be done at reasonable cost and deep enough to ensure permanency in cultivation

should the subsoil not be workable. In the reclamation of moss-land the necessary material for soil improvement should be easily obtainable.

Drainage.—The first essential in converting natural peat-land to arable land is drainage. Practically all peat-land needs draining. The fundamental principle in draining peat-land is to ensure sufficient outlet for rain and inflowing water, and if possible to prevent seepage from the surroundings. The main drainage-system should be supplemented by field drains, usually covered in; it aims at lowering the water-table to such a depth that the soil becomes sufficiently firm for bearing high-yielding crops. Two main points to bear in mind are the permeability for water of peat-lands, and the power of plant-roots to penetrate different types of peat.

Peat soils of the sedge type, which are but slightly decomposed and very porous, possess high permeability for water, whilst highly decomposed peat types are practically impermeable. In the former type the ditches can be spaced widely, in the latter they must be spaced closely. Plant-roots can easily reach ground-water level in the more permeable types, but they are checked in highly decomposed peat-land. Such soils are therefore liable to suffer when draining has been overdone. The yields from partly drained soils may often be high, but complete drainage is essential to procure crops of high quality. Depth of drainage is related to the spacing of the drains. Deep ditches can be more widely spaced than shallow ones. The distance between drains may vary from 70–80 times their depth on highly permeable soils to 12–20 times their depth on less permeable land.

Fens, mostly situated in hollows, are generally more difficult to drain than mosses, which often lie high and sometimes possess more than one natural outlet. An accurate diagnosis of the causes of water-logging is necessary to ensure successful drainage. Drainage of mud soils in shallow lakes should proceed slowly in order to give the mud time to settle firmly.

Several kinds of ditches are needed. The main ditches have already been mentioned. Diversion ditches are used to intercept the water from the surroundings; the water is directed by lateral drains to the main outlet, and finally a system of covered drains is laid out in the fields and leads into the open-ditch system. The closed drains may be of different types, such as tile drains, brush drains, wooden-box drains, poles and twigs, and even tubular drains. Wood being cheap in Sweden, wooden-box drains of different kinds are most commonly used for the closed-drainage system.

The inclination of the walls of the open ditches depends on the type of peat. In peat but slightly decomposed the sides can be made almost vertical; in highly decayed, loose peat soils they must be inclined. Where erosion may be expected, especially at the line between the peat and the underlying mineral soil, revetments of wood or stone should be used to strengthen the sides of the ditches.

Draining is most commonly done by digging; in parts of Norrland, it is done with water, a process which, although labour-saving, necessitates great care and elaborate planning.

Cultivation.—Certain peat-lands can be ploughed directly after draining, others need much preliminary working. Mud soils and many grass and sedge fens belong to the first group. Hummocky land has to be levelled with a scarifier or hoe, and the hummocks broken up with a harrow. Big areas are most quickly and economically cultivated with a 'Lanz' rotary-blade cultivator. The first cultivation should be shallow. When cultivating wooded land, the forest can be cut down first and the land cleared with a stump-extractor, or the bigger tree-roots cut and the trees pulled down. Another way is to blast the stumps, preferably in late autumn when the soil is frozen. When the area has been cleared, cultivation by hoe, harrow, plough, or rotary cultivator follows. The cultivation of moss peats is somewhat different. Where the surface is fairly even and hard a good seed-bed can be prepared by repeated harrowing. The best results are obtained if the soil is cultivated while the subsoil is still frozen and the surface soil is water-logged and loose. Soil ameliorants are added between cultivation operations.

Burning is often used for facilitating clearance work; it should be done early in the season while the surface is still frozen, and with due precautions to protect surrounding vegetation from catching fire.

The first cultivation operation, generally ploughing, should be done to a considerable and exact depth. A satisfactory plough for peat should have an elongated coulter and long thin share, in order that the slices should turn over completely, thus preventing the old vegetation from growing again and competing with the cultivated plants. All cutting parts should be kept sharp as knives. Tractor-ploughing can be advantageously used provided the wheel-surface is enlarged and fitted so as to avoid slipping on the loose soil. Necessary levelling is done with a scoop.

Soil amelioration.—Amelioration by mixing mineral soil, sand, gravel, or clay with a peat soil aims firstly at improving the physical properties of the peat. The improved peat soil becomes heavier, firmer, and more fertile, permeability and heat-conductivity increase, and water-capacity decreases. The new soil conditions promote the warming-up of the soil in spring and lessen risks of frost damage in autumn. Further, the soil structure is improved and the transformation of soil nitrogen is speeded up. The net result of the changes produced by amelioration is an increased yield. The following results of an 11-year trial in a hay-meadow illustrate the increase in yield by amelioration:

Amelioration	*Yield of hay (quintals per hectare)*	*Increase in yield*
None	32·6	..
Sand 200–400 cub. m.	42·5	9·9
Clay 100–300 cub. m.	54·4	21·8

An increase of 800–1,000 kg. hay, or corresponding amounts of other crops, can be expected, but the effect is often appreciably higher. The botanical composition of the herbage is also improved.

Amelioration is necessary on most badly decomposed peat soils and on all soils with an ash-content lower than 10 per cent. Clay is the best

ameliorant, then moraine gravel, and then sand. In Sweden the so-called 'sand *mixing*' is universal—not the 'sand *covering*' formerly used widely in Germany. The addition of 150–200 cub. m. of clay or 300–500 cub. m. of sand per hectare is recommended.

Cultivation costs.—Owing to the great variety of operations needed on different peat-lands, cultivation costs vary considerably, and it is therefore impossible to quote an average figure as a basis for economic calculations. Each case has to be considered separately. It is nevertheless of interest to investigate the expenses incurred under different circumstances, especially in the reclamation of poorer moss-peat soils, since the cultivation of level fenland is always profitable provided the draining can be done at a reasonable cost.

The average total cost per hectare of the experimental reclamations carried out in South Sweden is said to have been 450 kronor without, and 750 kronor with, amelioration.

Lime-status. Lime is applied after amelioration and before manuring. Although it is often possible to estimate the lime-requirement of a mineral soil from its pH value, that of peat soils is gauged by the lime-content per hectare of the peat to a depth of 20 cm. The soil-reaction values required on peat-land differ from those desirable for mineral soils, because the humus compounds of peat soils protect the plants from the injurious effects of free ions of iron, aluminium, and manganese, which are present in very acid mineral soils.

Formerly 3,000 kg. lime per hectare to a depth of 20 cm. was considered sufficient, but nowadays 5,000 kg. is regarded as the lowest limit. The higher figure is due to the replacement of physiologically alkaline manures, like basic slag and nitrate of soda, by physiologically acid or less alkaline manures. If the peat soil contains less than 5,000 kg. of lime per hectare, it should be limed to reach this value. A few years after the cultivation of highly calcareous soils, certain diseases may occur, which will be discussed later. The surplus lime in such peats is steadily increasing, owing to the continued oxidation of organic matter. In peats where the lime-content of a layer equal in depth to the yearly shrinkage exceeds the sum of the yearly leaching by rain *plus* uptake of calcium by plants, there is an appreciable increase of lime in that layer.

About half of the peat-lands in Sweden are lime-deficient; only in the island Gotland do the soils contain sufficient lime. The peat soils of west Sweden and parts of Norrland, where the rainfall is high, have high lime-requirements. Besides the lime necessary to correct the initial lime-deficiency, an application of about 1,500–2,000 kg. lime per hectare in the course of 7–8 years should be given to counteract losses incurred by leaching and uptake. The different kinds of lime have proved of equal value for peat soils.

Manuring.—Variations in the nitrogen-content of peat soils are great. Fen soils often contain 15,000–30,000 kg. nitrogen per hectare in the plough-layer and sometimes still more. All the nitrogen does not, however, exist in an available form, but provided that the soil conditions favour a transformation of the soil nitrogen to more available compounds, nitrogenous manuring is not necessary. On the other hand,

moss-peat soils are deficient in nitrogen, and nitrogenous manures in the same amounts as for mineral soils must be given to obtain good yields. Excepting some mud soils, all peat-lands are poor in potash and phosphate.

The disadvantage of the low plant-nutrient content of peat soils is, however, amply counterbalanced by favourable moisture conditions that promote the utilization of nutrients by plants. Regulation of the different plant-nutrients by addition of farm-yard manure and inorganic fertilizers is therefore of paramount importance in securing successful yields on peat-land.

Soils which respond best to farm-yard manure are the undecomposed, nitrogen-deficient moss-peat soils. This manure has a stimulating effect even on nitrogenous peat soils, especially when clover is grown, and should therefore never be entirely omitted; it is usually applied for potatoes, roots, and legumes, and sometimes on grass land. In most cases farm-yard manure needs to be supplemented with phosphatic fertilizer, often with a further addition of potash, and sometimes with nitrogen.

Potash and phosphate have to be applied every year, and it is advisable to give a liberal dressing of phosphate. When peat-land is reclaimed, a heavy initial dressing (500–1,000 kg.) of slag or superphosphate is given at the start, and can be repeated liberally the following year. The potash of peat soil is more soluble than the phosphoric acid, and is readily taken up by plants in spite of its low concentration. The response to potash dressings is therefore sometimes small during the first years. It is, however, desirable to give a basal dressing of potash in the reclamation of peat-land. The increases in yield due to both P and K fertilizers are normally considerable. On nitrogenous peat soils normal yields are often obtained after suitably manuring with P and K. As on these soils the yields would have been almost nil without the P and K dressings, the total yield may be regarded as the response to fertilizer-treatment. In most cases it is possible to procure high yields at low cost by well-balanced manuring; the cost of fertilizers for hay from permanent leys, for instance, often does not exceed 1–2 öre per kg. Superphosphate, basic slag, and bone-meal are the most commonly used phosphatic fertilizers on peat-land in Sweden, and all are equally effective on lime-deficient peats. The more soluble superphosphate acts rather more quickly than the other two fertilizers which, however, have a higher lime-content. Further, the manganese of basic slag is beneficial on certain soils. Forty per cent. potash salts are as a rule the most economical potash fertilizer per kg. of potash, but on some soils salts with lower potash-content are preferable on account of the effect of their other constituents.

Peat-lands display great variations in their requirements of nitrogen. Well-managed peat soils in south Sweden, containing 10,000–12,000 kg. nitrogen per hectare, require no further addition of nitrogen, except when nitrogen-hungry crops like roots and potatoes are grown. The nitrogen already present in these soils is sufficient for other plants, provided that the transformation of soil nitrogen is promoted by the presence of phosphate and potash in amounts necessary for microbio-

logical activity. Several instances are known where a balanced manuring of potash and phosphate has had the same effect as a dressing of nitrogen. On nitrogen-deficient peat soils, however, manuring with nitrogenous fertilizers is imperative for obtaining good yields. As long as the opinion prevailed that the nitrogen-content of a peat soil sufficed to produce normal crops, many peat soils were low yielding. There is no difference in the effectiveness per kg. of nitrogen of the three nitrate-nitrogen manures, except that 'Ljungasalpeter' (similar to nitro-chalk) seems to be superior for leys on calcareous peat soils. Sulphate of ammonia is used on fens, and calcium cyanamide is advantageously used on well-decomposed peat soils rich in mineral constituents.

A well-balanced manure not only gives higher and more reliable yields, but also raises the quality of the crop. This is very noticeable on peat-lands. The clover in permanent leys is especially responsive to dressings of P and K. Complaints were often made earlier that the hay harvested from peat soil was inferior in quality to that from mineral soils. Recent investigations have, however, shown that if peat soils are properly manured no such difference exists. It has been shown at the Flahult Experimental Farm of the Swedish Society for the Cultivation of Peat-land that economic results can be achieved on peat soils.

Diseases on peat soils.—With few exceptions, which will be discussed briefly, it is usually possible to obtain good yields on peat soils. It is, however, sometimes difficult to secure good grain crops. Several causes are possible, but it may often be a question of deficiency of one of the necessary minor elements, such as manganese or copper. Manganese-deficiency causes 'grey speck', and copper-deficiency 'yellow tip', of oats. The deficiency is often associated with too high a lime-content of the soil, which can be rectified by the use of acid fertilizers like sulphate of ammonia. In the case of copper-deficiency, however, it is often necessary to add the element itself. The results are sometimes impressive. One addition of 100 kg. of copper sulphate per hectare increased the grain-yield of oats up to 1,000 kg. several years running, in some experiments in central Sweden.

Crop-rotation.—When the reclamation of peat-lands started in Sweden half a century ago, there was a tendency to crop oats continuously on these soils. Oats are well suited for peat-land and at that time were profitable to grow. It was, however, soon discovered that continuous oat-cropping involved certain disadvantages, especially the increasing difficulty of keeping down weeds. Such continuous oat-cropping still persists, but on the better-managed peat soils rotational, or long-term pasture- and hay-management has displaced the older oat-cropping. As cultivated plants react very differently to peat soils, the suitability of the principal crops will be discussed briefly.

Wheat as a rule does not do well on peat. Autumn wheat can, however, be grown advantageously on certain mud soils, especially on those rich in clay or lime, and on shallow heavy fen soils well mixed with mineral soil in south Sweden. Spring wheat is also suited for these soils. At Flahult, spring wheat has yielded well on shallow fen soils, and the baking quality was higher than the average. Since spring wheat ripens

late, it should be cultivated only on peat soils in favourable situations, and it has to be sown earlier than any other cereal.

Rye on the other hand is especially well suited, the only danger being winter frost. Rye is more dependable on slightly decomposed soils, and is therefore a suitable crop on newly reclaimed moss-peat land. The ordinary rye strains are generally hardy enough for the peat soils of south and central Sweden. On the more decomposed peat soils or the older moss soils, it may be profitable to use midsummer rye, which is grown exactly as autumn rye, but sown early in the autumn. Midsummer rye possesses a strongly developed root-system that withstands frost-damage better than ordinary rye.

Barley grows well on all calcareous peat soils that are well supplied with nitrogen and not too loose. Barley grown on peat soils is, however, not considered good malting barley, since it is too high in protein and too low in carbohydrate. It is, however, excellent as fodder, for which the bulk of it is used. In trials conducted over several years at the experimental farm at Flahult on fen peat, the grain-yields of the best barley varieties were far superior to those of oats, sometimes reaching a value of 30 per cent. increase. A necessary condition for successful barley-growing is the absence of weeds. Barley has also the advantage of ripening earlier than any other cereal crop, which facilitates both harvesting and soil-cultivation operations. Only varieties with stiff straw should be selected for peat soils.

A poor crop of oats is sometimes obtained after potatoes or roots on peat-land. Trials at Flahult have shown that normal yields can be obtained if barley is substituted for oats. General experience and field experiments point to the advisability of increasing the areas under barley at the expense of oats.

Oats still remain an important crop in the rotation on peat-land, although the total area should be somewhat reduced. The crop grows well on all peat soils that are not too calcareous. Early oat varieties possessing stiff straw should be selected for growing on peat soils.

Mixed oat and barley cropping is often more advantageous than either of the cereals alone.

The cultivation of cereals on peat soils is rendered more difficult by lodging, especially on the fertile, highly nitrogenous fen soils. To avoid lodging, different measures may be taken, such as selecting suitable manures and stiff-strawed varieties, eradicating weeds, and so on.

It is also important to cultivate well, especially by rolling, which makes the soil firm and gives the roots better conditions for a firm grip. Loose peat soils should therefore be rolled both before and after sowing.

Legumes—peas, vetches, and beans—are suitable only as green forage-crops, preferably on moss-peat soils low in nitrogen. The best green-fodder mixture for this type of soil consists of oats, peas, and vetches.

Turnips are the only root crop well suited for peat soils, and are high yielding, especially on fen land. The best varieties are Bortfelder and Östersundom. On moss-peats, where an undecomposed peat-layer directly underlies the plough-layer, roots do not develop fully and should be substituted by potatoes. On heavy mud soils and fen soils with a volume

weight of 400–600 kg. per cub. m., both swedes and fodder-beets can be cropped successfully.

Potatoes are exceptionally well suited for peat soils. High yields are obtained on non-calcareous peat soils, but the best potato crops are grown on fen land. The eating quality of potatoes grown on peat soils is, however, not so good as that of potatoes cropped on mineral soils, the starch-content being lower and the consistency more watery and looser. As fodder-crop, the peat-land potato is high yielding. For a long period an average yield of 35,000 kg. per ha. was obtained on the Experimental Farm at Flahult, and in trials the best varieties gave up to 60,000 kg. per ha., equivalent to 10 tons of starch per ha. Potatoes grown in peat-land keep their health and vitality for a considerable time, and thus are well suited for seed; when these are grown on mineral soils the yields are often increased by 10 per cent or more. Seed potatoes have become a specialized crop on certain moss-peat lands.

Hay-leys and pastures.—Grass has a prominent place in peat-culture. The highly nitrogenous fen lands are best suited for herbage crops, but clover can be grown well on the poorer moss soils. Probably more than half of the peat-land area of Sweden is now under grass. Towards the north of Sweden the importance of grass increases and that of other cultivated plants decreases. Grass is grown on peat soils either in rotation with other crops or as permanent leys or pastures. The sowing of grass in rotation should be done with the usual clover-timothy mixture as the main constituent, bearing in mind that timothy should play a greater and clover a smaller part on fen lands. A small amount of white clover should also be included.

For leys intended to be down for more than three years, the mixture should also contain more durable strains of grasses, such as *Alopecurus* and *Poa palustris*, and for more fertile soils *Festuca pratensis* and *Dactylis glomerata*. In southern and central Sweden, where rotation is possible, the leys should be ploughed after 3 or 4 years, since, on soils poor in nitrogen, hay-leys would need more nitrogenous fertilizers than would be economically profitable.

Pastures constitute the most remunerative form of peat-land cultivation. All kinds of peat-land can be selected for this purpose, but if a choice is possible, only those soils which are less suitable for other crops should be selected. Adequate drainage is, however, an imperative condition, otherwise the sward will not be firm enough to bear grazing cattle, and the formation of hummocks cannot be prevented.

If the soil cannot be properly drained, it is better to use it for hay in the ordinary way. The simplest way to obtain permanent grazing-pastures is to separate an old meadow and sow in white clover and *Poa pratensis*. When pastures are first laid down on peat soils the seeds-mixture should be selected to give a good hay-ley for the first year, so as to enable the sward to get firm before grazing begins. The common seeds-mixtures for hay should be supplemented with 1–2 kg. white clover, 2–3 kg. *Poa pratensis*, and in south Sweden with some *Lolium perenne*. In north Sweden, and in places with high humidity, there is no necessity for admixing *Poa*, since strains of wild *Poa* usually appear after

a few years. The management of pastures is the same for peat soils as for mineral soils. Rolling with heavy rollers should, however, be done in the autumn after grazing and in the spring before grazing starts. The younger pastures on soils that crumble when frozen especially need rolling to promote evenness and closeness of the herbage.

There are many records of yields and profits from grassland-culture on peat soils, particularly at Flahult, where the oldest pastures are nearly 50 years old, and have been under control for 30 years. The yields at Flahult average 3,000 fodder units per hectare, and the cost per fodder unit, including all expenses—rent, cultivation, overheads, management, &c., is 7 öre (approximately 1*d.*).

Vegetable crops.—Certain vegetables, such as lettuce and cabbage, are well-suited for peat soils rich in nitrogen, provided the climate is favourable. This type of culture should be remunerative in the south and south-west of Sweden.

Rotations.—The rotation on peat soils has to be considered in relation to the general production-programme on the farm. If the peat soils are used only for producing hay and fodder, it is advisable to lay down 3-year leys alternating with 2-years spring corn—1-year oats and 1-year mixed cereal—on soils low in nitrogen. On the nitrogenous peat soils the leys and pastures can be left down for 4 or 5 years. When a potato crop is desired, the rotation should be: oats following the breaking up of pasture, legumes, potatoes or roots, followed by ley with a nurse crop of mixed corn, which is left down 3–5 years, depending on the nitrogen-content of the soil.

On the shallow fen soils the same rotation can be used as on mineral soils, e.g. the common 7-year rotation with fallow and autumn cereal. If these soils are fairly free from weeds the following rotation can be used with advantage: potato, barley, grass (2–3 years), rye, roots, and oats; or potatoes, barley, grass, green manure and fallow, autumn rye, roots, oats.

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THE RELATIVE IMPORTANCE OF SOW AND LITTER DURING THE GROWTH OF SUCKLING PIGS: A COMPARISON OF FOSTERED WITH NORMALLY REARED PIGS

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WITH the introduction of intensive methods of rearing pigs, and the development of highly fertile strains, the problem of combining productivity with effective control of mortality and unthriftiness has become important. A recent report [1], giving details of the losses from these causes among young pigs, indicates that insufficient attention has been paid to this aspect of pig production. During the last six years, observations made on the Large White herd of the Institute of Animal Genetics, Edinburgh, lead to the conclusion that much morbidity proceeds from inadequate nourishment of the suckling pig. Although errors of management are no doubt frequently responsible for deaths, yet the fact that the milk production of sows varies within wide limits suggests that, in many cases, fertility may have outrun the capacity of sows for feeding their litters, which, in an under-nourished condition, become more susceptible to accidents and diseases.

Investigation of this subject is rendered difficult by the lack of suitable techniques for estimating actual milk production. The weight of litter alone is an indirect method open to various criticisms, but as a final criterion by which sows are to be judged, it has great value. Any means, therefore, by which it may be made to represent breeding-value more closely should improve the efficacy of selection.

The chief objections to the use of weaning or other weights of suckling pigs are, firstly, that they are too subject to environmental fluctuations, and secondly, that they are ambiguous in the sense that they do not discriminate between the quality of the sows and their litters. Since the milk production of sows cannot be readily measured, it is usually impossible to determine whether differences in the growth of litters of suckling pigs should be attributed to heredity or to milk supply. In a previous paper it has been shown that considerable differences do exist in the milk production of single nipples, and that these are associated with marked differences in the growth of the pigs attached to those nipples [2]. Information of this kind is too difficult to obtain for it to be feasible to accumulate sufficient material for estimating the effects of heredity, and a complementary line of investigation has therefore been carried on, which partially overcomes the objections to basing judgements on weaning-weight. The method employed in this investigation has been the exchange of pigs between pairs of sows farrowing at approximately the same time in such a way that each sow reared a litter of which half consisted of her own pigs and half the other sow's pigs. The object of this report is to give a preliminary account of results

obtained. Up to the present the data are not extensive enough to justify either detailed statistical treatment or the drawing of far-reaching conclusions. What has been done by way of analysis is, however, sufficient to indicate that as an experimental technique, the exchange of half-litters can be of great value in the study of the growth of suckling pigs.

Method.—Provided the exchanging was effected during the 2nd to 4th days after farrowing, it was usually accomplished without much trouble. By this time the pigs had received the colostrum, but had not yet become strongly attached to their dam. It was not always feasible to ensure that the 'halves' were balanced in respect of either numbers, sex, weight, or age. If they were balanced at the beginning, losses by crushing, &c., sometimes unbalanced them, and it is possible that in some cases pigs were taken from a functional teat and forced to suckle one that had wholly or partially dried off. Objections on these grounds are met by assuming that the influence of sex and litter-size over the range involved is so small that the degree of unbalance existing may be neglected. Variation in age is necessarily slight and reflected in weight-differences which have been allowed for. Whether these assumptions are permissible is difficult to know, but as attempts to find out are usually defeated by the excessive variation from other causes, the question appears at present to be somewhat academic.

Nevertheless, in interpreting the results, the circumstances of the experiment should be borne in mind. It should be remembered also that during the first week of life there is a strong tendency for the largest pigs to attach themselves to the anterior nipples, which are usually the most productive, and that all the pigs tend to accustom themselves to suckling a particular nipple [3]. When an exchange is made after 4–7 days, the pigs which change their mother cannot find their usual places, and are obliged to accept a fresh nipple. If the fostered pigs are larger than the natural offspring, they succeed in occupying the best positions, if smaller they are forced to the rear. Weight appears to be the most important factor in determining this distribution of pigs along the udder. Whatever the initial weight, however, the weights of the pigs after 3 weeks or more of suckling are controlled principally by the productivity of the nipple which they have usually suckled.

In this experiment no data are available concerning the actual amounts of milk provided by the sows. It has to be assumed that, on the average, the fostered half obtained as much milk as the natural. This might not be justified if the fostered pigs had been appreciably smaller than the others and had been forced to suckle the less productive nipples. Since, however, the correlation between weight at time of exchange and weight at 3 weeks is only about +0·6 (see Table 4), it is clear that the largest pigs, during the first week, are only moderately successful in finding the most productive nipples. As there was a slight actual superiority in weight at the time of exchange of 0·16 lb. in favour of the fostered pigs with the paired sows, it seems reasonable to suppose that they were adequately compensated for the disadvantage of having to change their mother. In selecting pigs for exchanging, the main consideration was to make up litters as uniform in weight as possible.

For various reasons a number of litters were reared that were composed of pigs from two sows but were unaccompanied by other litters with the corresponding halves. Data from these litters will be treated separately.

Results.—As a first step in the analysis of the results, the average weights of the pigs at three different times were obtained for each of the various sub-groups. These weights, which are given in Table 1, suggest that, in comparison with the effect of initial weight, the effect of fostering is in itself of no importance. It is conceivable, however, that a real effect might be obscured by the effects of initial weight, and further analysis of the results to allow for this is made.

TABLE 1. *Average Weights at Time of Exchange and at 3 and 8 Weeks old. Numbers of Animals in brackets.* A *sows farrowed before* B *sows*

	Exchange		*3 weeks*		*8 weeks*	
	Own	*Fostered*	*Own*	*Fostered*	*Own*	*Fostered*
Unpaired sows (8) . .	2·7 (36)	2·6 (32)	9·1 (36)	8·2 (32)	23·4 (31)	19·4 (28)
Paired sows A (10)* . .	3·6 (43)	3·1 (51)	10·5 (43)	9·5 (51)	25·4 (34)	25·1 (34)
,, ,, B (10) . .	2·8 (51)	3·6 (42)	8·2 (51)	9·8 (42)	22·4 (35)	27·3 (35)
Total . .	3·0 (130)	3·1 (125)	9·2 (130)	9·3 (125)	23·7 (100)	24·2 (97)

* Only 7 pairs available at 8 weeks.

It is required to know whether the variation in quantity of the sows' milk accounts for all the observed variation in the growth of the litters, or whether there is some variation between litters as born that is not accounted for by differing environments in so far as those are conditioned by the sows. The litters as reared should provide an estimate of variation due to environment peculiar to each sow (including her milk), and since the litters as born were reared as 'halves' in different environments, their comparison should yield an estimate of the variation due either to congenital causes or to common environment during the time from birth to transfer (usually 2–4 days).

TABLE 2. *Mean Weights at Time of Exchange and at 3 Weeks with Number of Animals in each Half-litter*

Sow A						*Sow B*					
Own (A)			*Fostered (B)*			*Own (B)*			*Fostered (A)*		
n	*Exchange*	*3 weeks*	*n*	*Exchange*	*3 weeks*	*n*	*Exchange*	*3 weeks*	*n*	*Exchange*	*3 weeks*
7	3·7	10·6	5	3·8	9·3	6	4·2	10·5	5	3·7	9·5
2	3·8	12·4	5	4·0	10·1	3	3·5	11·2	4	4·0	12·0
4	2·9	11·2	4	2·4	10·0	6	2·2	9·9	4	2·8	12·2
7	4·1	11·8	5	3·3	10·2	6	2·4	5·9	4	3·8	10·2
4	5·3	10·5	3	3·4	6·9	6	2·9	6·3	4	5·6	10·2
2	3·1	12·0	6	2·1	11·8	4	2·3	7·8	4	2·8	9·5
3	2·4	8·5	4	2·5	11·2	6	2·8	11·8	4	2·1	8·0
4	3·2	9·5	8	2·5	7·2	4	1·9	3·7	3	2·9	7·9
5	5·5	10·1	5	4·2	8·8	6	3·1	6·4	4	5·5	9·4
5	2·3	7·9	6	2·8	9·2	4	2·9	8·6	6	2·4	9·3
Total 36·3		104·5		31·0	94·7		28·2	82·1		35·6	98·2

The statistical method adopted has been to calculate first the average initial and 3-week weights for each 'half'-litter (Table 2), and then to analyse the variance and covariance of the differences and sum arising from them (Table 3). Since it was not possible to arrange that each

half-litter should be of equal numbers, it has been thought best to use their mean weights. This avoids the complications of unequal numbers but involves the assumption that size of litter makes no difference to the weight-increase. Such an assumption is unlikely to be true if large litters were to be compared with small, but if, as here, litters are considered in pairs of similar size (except the eighth pair in Table 2), the influence of litter-size may be regarded as immaterial. From the differences given in Table 3, it seems unlikely that fostering has had any ill effects, but there has apparently been a tendency for Sow A to rear better pigs than Sow B, and for the litter farrowed by Sow A to do better

TABLE 3. *Mean Differences and Sum from Table 2*

Sow A − Sow B		*Own − Fostered*		*Litter A − B*		*A + B*	
Exchange	*3 weeks*	*Exchange*	*3 weeks*	*Exchange*	*3 weeks*	*Exchange*	*3 weeks*
−0·4	−0·1	+0·4	+2·3	−0·6	+0·3	15·4	39·9
+0·3	−0·7	−0·7	+1·5	+0·3	+3·1	15·3	45·7
+0·3	−0·9	−1·6	−1·1	+1·1	+3·5	10·3	43·3
+1·2	+5·9	−0·6	−2·7	+2·2	+5·9	13·6	38·1
+0·2	+0·9	−0·8	−0·3	+4·6	+7·5	17·2	33·9
+0·1	+6·5	+0·5	−1·5	+1·5	+1·9	10·3	41·1
0·0	−0·1	+0·6	+1·1	−0·8	−6·5	9·8	39·5
+0·9	+5·1	−0·3	−1·9	+1·7	+6·5	10·5	28·3
+1·1	+3·1	−1·1	−1·7	+3·7	+4·3	18·3	34·7
−0·2	−0·8	0·0	−2·0	−1·0	−0·6	10·4	35·0
Total +3·5	+18·9	−2·1	−6·3	+12·7	+25·9	131·1	379·5

than the litter of Sow B. Both sets of comparisons, however, are still complicated by the effects of weight at time of exchange. By analysing the variance and covariance of the data in Table 3, it is possible to eliminate from the comparisons the influence of initial weight, and at the same time to compare the variance of the three differences and the sum. These variances may also be compared with an estimate of the variance of the means of half-litters regarded as a measure of random error.

An analysis of variance on these lines is given in Table 4. It will be observed that in the first and second lines no mean has been taken out, since there is no reason to suppose that A sows and litters are different from B sows and litters, and the degrees of freedom are therefore 10. In this way a test is made of the null hypothesis that the differences between sows (i.e. litters as reared) and litters as born do not vary significantly from zero when compared with the error variance.

In preparing the estimate of error, Yates' method [4] has been used, in which allowance is made for unequal numbers in the half-litters by multiplying the sum of the variances within the half-litters by the sum of the reciprocals of the numbers in each half-litter. In the present instance the sum of the reciprocals amounted to 0·23485, which is to be multiplied by 4, giving 0·9394, since each entry in Table 3 is made up of 4 values from Table 2.

With the removal of the variance due to regression of final on initial weight, there has been a considerable reduction of the mean square in all the lines except the fourth. Even so, the remaining variance is large enough in the Sow A − Sow B, Litter A − Litter B, and A + B lines to be significantly greater than that occurring in the half-litters. Given an

error variance of 2·047, and n_1 and n_2 equal to 8 and 150 respectively, the minimum mean square for significance at the 5 per cent. point is about 4·1, and at the 1 per cent. point about 5·3. The evidence thus indicates that the differences between litters as born and as reared, and between pairs of litters, are too large to be accounted for in terms of the estimated error variance. The superiority of the fostered pigs, on the other hand, is well within the limits of error.

TABLE 4. *Analysis of Variance of 3 Weeks' Weights adjusted for Weight at the Time of Exchange*

	D.F.	*(Init.)²*	*Init. × Final*	*(Final)²*	*D.F.*	*Sums of squares*	*Mean square*	
Sow A−Sow B	10	3·89	15·63	115·45	1	62·80	..	..
					9	52·65	5·85	SS.
Litter A−Litter B	10	48·13	87·69	219·97	1	159·77	..	..
					9	60·20	6·69	SS.
Own−fostered:								
Within	9	3·13	3·97	26·12	1	5·03	..	..
Mean	1	0·44	1·32	3·97	8	21·09	2·64	NS.
A+B	9	94·85	−7·76	233·62	1	0·63	..	..
					8	232·99	29·12	SS.
Within half-litters	147	39·72	86·65	487·89	1	189·03	..	..
					146	298·86	2·047	..
			r (within half-litters) + 0·62					

NS. = non-significant; SS. = significant at 1 per cent. point.

The coefficients of regression of 3-week on initial weight calculated from each line are as follows:

Sow A−Sow B	+4·018±1·23
Litter A−Litter B	+1·822±0·37
Own−fostered	+1·268±0·92
A+B	−0·082±0·55
Within half-litters	+2·182±0·227

With the exception of the regression derived from the A+B column of Table 3, they agree in showing the importance of initial weight on final weight. Since the four positive coefficients are not significantly different, a further test of the significance of the sow- and litter-differences can be made using combined estimates of the regression variance in the manner shown in Table 5. Here the estimate of regression variance from the half-litters is combined with the estimate from the sow- and litter-differences separately. Whether it is in order to use an estimate from intra-sow data to adjust inter-sow comparisons may be doubted: the correct procedure would presumably depend on the extent to which the factors determining the regressions were the same within and between litters. In so far as the regression within litters depends on the fact that a light pig has naturally a slower growth-rate than a heavier pig, it is likely to correspond with the regression arising from inter-sow differences, but actually it is probably affected considerably by competition among litter-mates for the anterior nipples. Whichever estimate of the regression is used, it may be concluded that, from time of exchange until 3 weeks after farrowing, under the conditions of this experiment, real differences have been introduced by the sows in respect of milking capacity, and by the litters as born in respect of ability to grow.

The absence of a regression between the sums of the pairs of litter means is somewhat unexpected. The explanation is possibly that seasonal or other factors affecting both sows of a pair equally have modified 3-week weight independently of initial weight, although this weight retains an influence which can still be measured by intra-pair comparisons. That there was a great deal of variation from one pair of sows to another in the mean 3-week weight of their litters is shown by the A+B line of Table 4. A large mean square in this line is to be expected, because seasonal and genetical differences between the pairs are combined. It does not appear possible, unfortunately, to arrive at a direct evaluation of the relative importance of environment and heredity, since each source of variation may contain the influence of both. The

TABLE 5. *Further Test of Significance of Sow A—Sow B and Litter A—Litter B Differences*

	D.F.	$(Init.)^2$	*Init.* × *Final*	$(Final)^2$	*Residual sum of squares*	*Mean square*
Sow A—Sow B+within half-litters	157	43·61	+102·30	603·34	363·37	
Subtract residual sum of squares for half-litters alone	147	..	..	..	298·85	
Sow A—Sow B	10	..	..	..	64·52	6·452
Litter A—Litter B+within half-litters	157	87·86	+174·36	707·36	361·34	
Subtract residual sum of squares for half-litters alone	147	..	..	..	298·85	
Litter A—Litter B	10	..	..	..	62·49	6·249

sow comparisons, for instance, have not been freed of age-differences, nor of the effects of previous history, such as size of previous litters (which may have affected udder-development), and they are hardly worth further consideration. The litter-differences, on the other hand, having been adjusted for initial weight, might be justifiably regarded as genetic in origin; but even here it is possible that something may have happened to the pigs *in utero*, or during the first few days on their own mother, which may have affected their later growth.

Analysis of the 8-week weights.—Between the ages of 3 weeks and 8 weeks the growth of suckling pigs outruns the available milk supply, which is supplemented by solid food in increasing quantities. The amount of milk consumed at 8 weeks of age is nevertheless in the neighbourhood of 40 per cent. of the total food consumption [5], and it may be safely assumed that the milk production of sows is important at all ages of the suckling pig. Thus variation in the average weight of litters at 8 weeks may be readily accounted for by differences in milk production, and although food is only one item in the environment peculiar to each litter as reared, the available evidence suggests that it is the most important item. As the experimental results under discussion were obtained with pairs of litters kept under conditions as similar as possible with separate penning and standard feeding, the observed differences between average weaning-weights may be even more properly attributed to variation in milk production. The significance and importance of these differences may be judged from the Sow A—Sow B line of Table 6, which has been constructed in the same way as Table 4,

although unfortunately only 14 sows are available for comparisons at the later age.

It is noteworthy that the variance of the A+B line has become smaller than that of the Sow A—Sow B line, although still significant at the 1 per cent. point. This could be explained by either a lessening of the effect of seasonal influences on the pairs of litters when milk is being supplemented by meal, or more probably by an exaggeration of the differences between sows, because the first litter (as reared) to eat solid food will draw rapidly away from the other until it also starts trough-feeding. Thus relatively small differences between sows at 3 weeks might become much larger at 8 weeks if no further differences arose between them. Judged by the present data, the elimination of the effect of weight at 3 weeks on the final weight at 8 weeks shows that milk production up to 3 weeks does have a considerable influence on the 8-week weights (see Table 7). The differences Litter A—Litter B are no longer significant, but in view of the small numbers and the large error variance, the possibility that real differences do exist cannot be disregarded. The effect of fostering is again shown to be negligible.

TABLE 6. *Analysis of Variance of 8-week Weights adjusted for Weight at Time of Exchange*

	D.F.	$(Init.)^2$	*Init.* × *Final*	$(Final)^2$	*D.F.*	*Sums of squares*	*Mean square*	
Sow A—Sow B	7	1·93	+12·19	727·20	1 6	76·99 650·21	.. 108·37	.. SS.
Litter A—Litter B	7	29·81	+134·55	791·44	1 6	607·30 184·14	.. 30·69	.. NS.
Own—fostered:								
Within	6	1·61	−8·49	59·15	1	44·77	..	..
Mean	1	0·24	+2·12	18·57	5	14·38	2·88	NS.
A+B	6	45·32	−77·56	478·63	1 5	132·74 345·89	.. 69·18	.. SS.
Within half-litters	97	32·73	+94·80	2,212·95	1 96	274·58 1,938·37	.. 20·19	.. ..
			r (within half-litters) + 0·35					

NS. = non-significant; SS. = significant at 1 per cent. point.

As judged by the regression variances of Table 6, the weight at time of exchange is still responsible for a considerable amount of variation in individual weight at 8 weeks. Adopting the criterion that with an error variance of 20·19 any regression variance over 80 is significant at the 5 per cent. point, it will be seen that within half-litters and between the mean differences of Litter A and Litter B, initial weight maintains a significant degree of importance. In the Sow A—Sow B line, however, it is no longer significant; and in the Own—Fostered line it remains insignificant. The sums of the pairs now show a negative covariance leading to a significant regression variance. Interpreted in the light of experience, these findings must mean that where competition exists (e.g. within litters), initial weight is important in determining distribution along the udder and therefore final weight, but where competition does not exist (e.g. between one sow and another, or between pairs of sows), or where it is only partial (e.g. between Litter A and Litter B), the

degree of importance of initial weight depends on the correlation between it and milk supply. If light initial weight happens to be associated with heavy milk production, it will involve no disadvantage, except where there is competition. If the available milk is substantially the same for different litters, initial weight may be expected to influence final weight, even where there is no competition, merely because the heavier of two animals growing at the same relative growth-rate will remain the heavier. These considerations are presumed to account for the positive regressions observed previously of 3-week weight on initial weight, where competition has been absent or partial.

The 8-week weights may also be adjusted for variation in 3-week weights, and the importance of sow and litter considered independently of the latter. This has been done in Table 7, which is to be compared with Table 6. The sow-differences are still too great to be due to random variation, and are therefore suggestive of differences in milk production between 3 and 8 weeks after farrowing, although the effects of other uncontrolled environmental factors have still to be measured. Investigations of this kind are liable to be complicated by gradations of unthriftiness due to anaemia and other troubles which do not lend themselves to measurement. In general, they are likely to exaggerate real differences in milk production, since under-nourished animals are more prone to contract them.

TABLE 7. *Analysis of Variance, in which the Variance of the Final Weight at 8 Weeks is adjusted for the Initial Weight at 3 Weeks*

	D.F.	$(Init.)^2$	*Init.* × *Final*	$(Final)^2$	*D.F.*	*Sums of squares*	*Mean square*	
Sow A—Sow B	7	76·98	+151·19	727·20	1	296·94	..	..
					6	430·26	71·71	SS.
Litter A—Litter B	7	109·18	+255·85	791·44	1	599·55	..	..
					6	191·89	31·98	NS.
Own—fostered:								
Mean	1	1·12	+4·56	18·57	1	0·27	..	..
Within	6	18·14	+2·23	59·15	5	58·88	11·78	NS.
A+B	6	111·60	+162·78	478·63	1	237·43	..	..
					5	241·20	48·24	S.
Within half-litters	97	373·65	+431·87	2,212·95	1	499·16	..	..
					96	1,713·79	17·85	..
			r (within half-litters) +0·47					

NS. = non-significant; S. and SS. = significant at 5 and 1 per cent. points.

No important alteration has occurred in the Litter A—Litter B, or the Own—Fostered lines. The mean squares in the remaining three of the five lines have been reduced as a result of increased dependence of 8-week weight on initial weight, in this case 3-week weight. Thus variations in 8-week weights are to some extent due to magnifications of differences existing 5 weeks previously. In terms of correlation coefficients calculated from the half-litter lines, the dependence alters from 0·35 for exchange and 8-week weights to 0·47 for 3- and 8-week weights. The small value of these figures indicates that even within the restricted conditions of individual litters, the passage of time is accompanied by considerable changes in the distribution among litter-mates of environmental factors favourable to growth.

As a further proof that fostering *per se* does not contribute a significant amount to the variability of litter-mates, the following figures derived from eight unpaired sows may be presented. Litter and sow comparisons are not possible and the value of the data lies only in the comparison of fostered with naturally-reared litter-mates. As before, the mean differences of the two 'halves' have been squared and their products computed to provide the material for the adjusted estimate of the mean square. This last is to be compared with the corresponding error mean squares from half-litters (given in previous tables), which, although not derived from the same information as the treatment mean squares, are considered to be better estimates of error variance. The treatment variance is again less than the error variance.

TABLE 8. *Test of Significance of Differences arising between Fostered and Naturally-reared Suckling Pigs*

	D.F.	*(Init.)²* *(Exchange)*	*Init.* × *Final*	*(Final)²* *(3 weeks)*	*D.F.*	*Sums of squares*	*Mean square*
Own – fostered	7	0·26	−0·30	9·85	1	0·35	..
					6	9·50	1·583
Error variance (from Table 4)	..	..	..	..	146	..	2·047
		(Exchange)		(8 weeks)			
Own – fostered	7	0·38	+5·70	154·25	1	85·50	..
					6	68·75	11·46
Error variance (from Table 6)	..	..	..	..	96	..	20·19

Discussion

As shown in the preceding pages, the relative importance of sow and litter at any stage of suckling can be calculated without loss of essential information. According to the kind of information that is sought, modifications in the method may easily be introduced. In the present instance, it was merely desired to know what amount of variation in weaning-weight might be attributed to sows and what to their litters, the intention being to investigate further that source of variation which was the most important under Shothead conditions. Under other conditions the results may be different, and it may be desirable to make comparisons of breed and strain of suckling pig with sows controlled, or of seasonal effects with heredity of sow and litter controlled. For these purposes it would be necessary to select sows and litters for exchanging rather than to pair them quite at random as was done in this case. The distinction that has been made between Sow A and Sow B would then come to have some meaning, and the variation of the pairs about their common mean acquire a greater significance. Further, the exchanging might be extended with advantage, the limit being reached when a group of, say, 10 sows each reared one pig from each. From less complicated experiments than this a very fair estimate of seasonal effects might be obtained from what would correspond to the A+B column of the foregoing Tables 3 and 4.

The results of the present restricted series of exchanges indicate that the most conspicuous feature has been the environment of the litter as reared, i.e. either milk production or other sow-conditioned influences have been of greater significance than any other source of variation. This is in accord with the previous findings from similar pigs [2], which indicated that the growth of suckling pigs was in close relation to the amount of milk they obtained. There is nothing unexpected about this result, but it is as well to be certain that any attempts to improve the development of pigs in the suckling stage should be properly directed. While attacking the problem from the dam's side, it should not be forgotten that evidence of litter-differences has been found in the 3-week weighings. These differences have the appearance of being hereditary, but more extensive material is desirable before finally accepting the present results. Whatever their cause, however, they were as important as sow-differences at 3 weeks, and although they produced no further significant effects between 3 and 8 weeks, the differences existing at 3 weeks had a very substantial influence on the 8-week weights. With the improvement which might be expected from the elimination of many of the poor-milking sows, litter-differences would acquire an enhanced importance.

Summary

The relative importance of sow and litter in determining the variation of the weight of suckling pigs has been investigated by means of paired litters farrowed at approximately the same time and divided each into two groups of pigs, one of which was left on its own mother, and the other transferred to the second sow in exchange for a similar group.

Preliminary results from twenty litters reared in this way indicate that in those litters an equal and significant amount of variation in the growth of the pigs up to 3 weeks was found between litters as born and litters as reared. A larger portion of the variation was produced by differences in the totals for each pair of mixed litters. This is attributed to a combination of genetical and seasonal causes.

The weight of the pigs at 8 weeks was found to be influenced considerably by the sow, but, when adjusted for variation in weight at 3 weeks, showed that the effect of litter as born was no longer significant.

Weight at time of exchange was found to affect both 3- and 8-week weights, the coefficients of correlation being 0·62 and 0·35. Between 3- and 8-week weights the correlation was 0·47. No ill effects from fostering could be detected under conditions in which the fostered pigs had equal chance with the naturally-reared litter-mates.

It is concluded that under Edinburgh conditions the most important factor in the growth of suckling pigs is the milk production of the sows. The significant differences between litters as born are suggestive of hereditary effects, but confirmation of this is desirable.

On the basis of the observed results, it is suggested that the exchanging of litters in some form would lead to useful results in a variety of investigations concerning suckling pigs.

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THE CONSERVATION OF FORAGE CROPS WITH SPECIAL REFERENCE TO GRASS

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THE conservation of forage crops for use by stock in periods when there is no growth was one of the earliest problems of agriculture. Drying by natural means was the obvious solution, and to-day haymaking is still the most general process of conservation. Artificial drying is the sequel to the difficulties which beset any system of natural drying, apart altogether from the fact that the latter is usually possible only at a fairly advanced stage of growth when the feeding-value is relatively low. It is interesting to note that efforts were being made to improve the haymaking process by artificial drying in Great Britain as long ago as 1869 [1], when the Royal Agricultural Society of England tested a number of dryers.

The third possibility is the conservation of the fresh crop under conditions that preclude undesirable fermentation. This is the process of silage-making or ensilage, and the underlying principles are straightforward. They are, simply, the exclusion of air by proper compaction, and the rapid production of the proper degree of acidity in the mass, either by direct addition of weak acid solutions or the stimulation of lactic-acid formation by the flora present on the fresh herbage. Another aspect of the conservation of the fresh crop is the treatment of the fresh material in such a way as to prevent all micro-organic action by destroying the enzymes as well as the bacteria contained in the green crop.

Nutrient losses in conservation.—Much information has been collected concerning the losses of nutrients involved in the different processes, and these are summarized in Table 1, which is based on a survey of the literature on conservation [2]. The first point to notice is that the losses of dry matter are much lower than the losses of starch equivalent, the truer measure of the nutritive value, the reason being that the losses always fall on the most easily digestible fraction of the dry matter. The dry-matter losses are often quoted, but are really of little value in assessing the relative efficiency of the different conservation processes.

Haymaking, the most common process, shows the highest loss of starch equivalent, and is exceeded in loss of digestible crude protein only by the ordinary silage process. It should be stated in extenuation that the figure for this type of silage includes silage made in the clamp or stack, a process always subject to high losses of digestible crude protein on account of the depressing action of high temperatures in the mass on the digestibility of this constituent. This is a point to which we shall have to refer again later.

Even under normal conditions, what would be called good hay loses some two-fifths of the starch equivalent of the original crop and one-third of the digestible protein during making. Crasemann and Steiner [3], among others, have shown that in bad weather the losses are still higher,

especially when the 'half-made' hay has been subjected to the leaching action of rain.

So obvious is this fact that in many parts of the world it is everyday practice to use stakes, tripods, hurdles, or wire racks on which to dry the hay. These prevent the mechanical loss of dry leafy parts and also shed the rain from the partially dried crop. Such appliances, it will be seen, give an advantage of about 5 per cent. of starch equivalent and 10 per cent. of digestible protein. Crasemann and Steiner [3] have

TABLE 1. *Percentage Losses incurred in Conservation Processes*

Process	*No. of tests*	*Dry matter*	*Starch equivalent*	*Digestible crude protein*	*Digestible 'true' protein*
Haymaking	39	22·1	43·9	34·6*	37·0
,, with special appliances	96	17·4	38·2	25·3†	28·6‡
Artificial drying	2	7·5	11·5	8·2	1·1
Ordinary ensilage	255	15·9	34·3	39·8	67·4
Stimulated ensilage	34	11·7	22·9	10·0	58·1
Acidified ensilage	74	12·4	23·7	10·0	40·7

* Based on 32 determinations.
† ,, 3 ,,
‡ ,, 96 ,,

shown that this advantage applies only to bad weather; in good weather drying on the ground may be better, since it is then the more rapid. Artificial drying is the most efficient process, and the figures quoted in Table 1 are almost certainly on the high side, as they were obtained on an early experimental dryer at Jealott's Hill. This is borne out by the low values obtained in four tests made in Germany [4] with a band dryer. The figures do not extend beyond the loss of dry matter, but the average value for this constituent is reduced to 1·3 per cent. if they are included. It is obvious that artificial drying is the most efficient process of conservation as, of course, it should be, since it obviates respiration in the field and mechanical losses of leafy matter, and there is no subsequent fermentation in the stack to take a further toll of the original nutrients. The digestible 'true' protein shows a high recovery, because the drying process raises the percentage of 'true' (copper precipitable) protein in the crop.

When considering the losses in silage, it will be noted that all show high values for digestible 'true' protein. This is because in all methods of making silage the protein is broken down. In good silage this break-down does not go past the stage of the amino-acids, and the products should, therefore, not have lost their feeding-value. Kirsch and Jantzon [5], and Watson and Ferguson [6], have shown that the break-down products of the protein in silage have a higher feeding-value than the digestible 'true' protein figures would indicate, and suggest the use of the digestible crude protein as a better measure of the feeding-value of the nitrogen. Edin, Berglund, and Andersson [7] tacitly assume that the break-down products of protein in good quality silage are of equal

value to the original 'true' protein in the fodder, and quote figures for digestible 'true' protein and digestible crude protein equivalent to original 'true' protein, with a proviso that this applies only to silage of good quality and low volatile-base content. Morris, Wright, and Fowler [8] have also shown that the biological value, for milk production, of the nitrogen of good silage does not differ appreciably from that of the fresh crop. Recent work by Hart [9] at Wisconsin shows that we cannot overlook the possibility that the volatile bases, such as ammonia, may themselves also have a high feeding-value.

The general trend of all modern work is to show that the content of digestible crude protein is the more accurate measure of the value of the nitrogen for feeding to ruminants.

On this basis the modern processes of ensilage show very low losses of digestible protein, a most valuable point in their favour. The stimulation of the lactic-acid formation was brought about mostly by the addition of sugar in solution, or milk-sugar (as whey), and in some cases bacterial cultures were added, though, generally speaking, the fresh herbage has a sufficient flora for the purpose of producing the lactic acid needed.

The acidified silages were those in which solutions of mineral acids had been added in order immediately to produce the desirable acidity in the mass.

The losses of starch equivalent in the two last-named groups are low in comparison with those incurred in haymaking or in ordinary ensilage, where no additions are made. The figures for losses may be lower than the average quoted, but in well-made silage should not greatly exceed these values under practical conditions. Lower values are often reported from small-scale and laboratory experiments, but these are not always applicable to field conditions where control cannot be so accurate.

The ordinary silage is penalized by the inclusion of stack and clamp silage, and though these processes will not greatly increase the loss of dry matter, they do reduce the digestibility of the material, and particularly that of the protein. The following examples [10] make this clear:

TABLE 2. *Composition, Digestibility and Feeding-value of Grass Silage made in a Stack and in a Simple Wooden Portable Container*

	Stack		*Portable container*	
	Crude nutrients as per cent. of dry matter	*Digestibility, per cent.*	*Crude nutrients as per cent. of dry matter*	*Digestibility, per cent.*
Crude protein	18·92	41·7	18·37	68·0
'True' protein	15·30	30·1	12·36	52·4
Ether-extract	2·86	57·0	4·09	65·8
N-free extractives	32·47	49·2	40·20	67·3
Crude fibre	31·34	83·8	26·43	70·3
Starch equivalent	40·6		49·2	
Digestible crude protein	7·88		12·48	
Digestible 'true' protein	4·61		6·48	

The stack silage would have been classed as a good sample, dark in colour but palatable; the other silage was made from grassland herbage at a similar stage of growth in a simple wooden container, which was removed after the mass had settled. The greater compression possible at the sides reduced the temperature to the desired level of 80–100° F., and the all-round improvement in digestibility and feeding-value is obvious from the table. Ordinary silage, made carefully, from a crop at the correct stage of growth in a suitable container will give values nearer to those obtained for stimulated or acidified silage; though the loss of starch equivalent will be nearer 30 per cent., the loss of digestible crude protein can be reduced to about 10 per cent.

Vitamin-content.—One of the valuable points about any green crop is its vitamin-content. Of the vitamins in the growing plant the most important is vitamin A or, rather, its precursor, carotene. Vitamin D is also important, but is not present in very large amounts in green foods. The incidence of light is a complicating factor, which has a marked effect on the utilization of this vitamin.

Carotene is destroyed by oxidation, and during the process of making hay it is almost completely lost. Any speeding up of the process will tend to raise the amount present in the finished hay, but at the best the value is low as compared with that of the fresh crop. The use of racks tends to produce a hay of higher carotene-content, but it is still very low. In artificial drying the rapidity of the process prevents the destruction of the carotene, and in an efficient dryer the loss is probably of the order of 25 per cent. This may be increased during storage, and in extreme cases the loss from dried grass may be as high as in hay. With properly baled material, however, though the outside may bleach, the retention of carotene is high.

Fagan and Ashton [11] have shown losses of carotene during artificial drying which vary within wide limits, the average being 33 per cent. In well-made silage there is a fairly high retention of carotene if the content in average samples be taken as a guide, and where mineral acids are added, as in the A.I.V. process, it may be very high indeed. Peterson, Bohstedt, Bird, and Beeson [12] found a complete recovery in A.I.V. silage made from lucerne.

The average contents of carotene in the conservation products are of the following order:

TABLE 3. *Carotene-content of Conservation Products*

	Carotene, mg. per 100 gm. dry matter
Hay	1–3
Hay made with special appliances	up to 10
Ordinary grass silage	nil to 30
Artificially dried grass	25–35
Grass silage made with added sugary materials or weak acid solution	25–35

These figures can be no more than a rough guide, and wide variations will occur. The low value of hay is easy to see, and even under the best conditions the value is not high. Ordinary silage may be very variable

indeed, and if high temperatures have obtained, as is common in the stack, there may be no carotene at all in the finished product. In well-made silage the value may rise to as much as 30 mg. per 100 gm. of dry matter. Artificially dried grass varies considerably, according to its quality and also the storage conditions. A good sample should seldom show values under 25 mg. per cent., and values well above 35 have been obtained under the most efficient conditions. With the modern silages there is also likely to be a considerable variation, but the values in the table should not be difficult of achievement. In some cases higher values still may be registered, but this is not usual.

It should be noted here that the carotene is often stated in terms of mg. per kilogram, which gives values that are ten times those in Table 3. Then, again, it is common to find the figure expressed as total carotenoids, in which case one-third can be taken as carotene without great error, the remainder being xanthophylls, which always outweigh the carotene.

Vitamin C, ascorbic acid, is present in green crops, and is destroyed almost entirely in haymaking [13], whilst half is retained in A.I.V. silage. In other types of silage the losses will be much greater and usually almost complete, as is also the case with artificially dried crops. Lack of vitamin C in such fodders is of little moment with the ruminant. The vitamin-B complex is not present to any extent in green crops and need not be considered; nor do we know sufficient about vitamin E to discuss it at any length.

Concentration.—The concentration of the nutrients in any conservation product is of considerable importance, though it is often overlooked. By its very nature, hay is a roughage of relatively low nutritive value and often very low in digestible crude protein [14]; but this does not apply to lucerne hay, which is a most valuable source both of protein and of mineral matter, though a poor source of starch equivalent. Where maize can be grown and made into silage it gives a product of high starch-equivalent value, though very low in protein and mineral matter, and such silage is the ideal complement to lucerne hay. Maize silage alone is ill-balanced, and must be reinforced by protein and mineral matter.

Neither maize silage nor ordinary hay, meadow or 'seeds', can therefore be used in the production ration of stock; they are not sufficiently concentrated. The result has been a tendency to conserve material at an earlier stage of growth to produce a more concentrated feeding-stuff, even if the bulk produced is less. The aim of conservation is not only to produce the greatest bulk of fodder per acre, but to supply materials that can be utilized as nutrients adequate for growth, milk production, or live-weight increase, without recourse to purchased foodstuffs. This end can never be achieved unless a proportion of young material is conserved along with the more mature crop which is at present conserved as hay or ordinary silage (e.g. maize, vetch-and-oats). To do this, artificial drying or the modern methods of ensilage, with added sugary materials or acids, are a necessity. Generally speaking, hay, artificially dried grass, and silage will all produce the results, when fed to farm stock, which would be expected from their composition and digestibility.

All three are eaten readily, and can be given with safety to all classes of stock.

Present position of haymaking.—The making of hay is still the most important method of conservation in the greater part of the world. The trend is to mechanize the process in order to gain time and get the crop under cover more quickly. In this connexion Cashmore [15] has shown that windrowing or tedding, immediately after cutting, reduces very considerably the time necessary for complete drying.

The widespread use of racks and other haymaking appliances in certain countries, especially northern Europe, has already been stressed, and may be regarded as everyday practice in those districts.

Considerable interest has been devoted to baling of hay in the field, both in America and at Oxford [15]. This practice entails the handling of hay at a higher moisture-content than is possible under ordinary methods of stacking, the subsequent curing taking place in the bale. This results in a greater retention of the leafy part of the hay with benefit both to the protein-content and the carotene retained by the final product. Any such advantage would, however, not be expected greatly to exceed that obtained by the use of the special hay-drying appliances mentioned above and included in Tables 1 and 3.

Present position of artificial drying.—The fact that crops can be dried without loss of nutritive value has been proved beyond doubt, and large numbers of dryers are operating in Great Britain. The position has developed into the engineering problem of producing an efficient and economic dryer, and the more difficult problem of fitting it into the management of the average farm. One of the greatest difficulties has been to produce material of high protein-content throughout the whole drying season [16]. On aerodromes and on farms where dried grass is produced as a saleable crop, the management has been less difficult, since stock are of secondary importance.

The production of a suitable small-scale farmer's dryer has not been so successful as had been hoped, the capital cost being too high as yet. Slade [17] has, however, recently designed a cheap dryer that can be erected by the handy farmer and appears to have considerable promise.

The position of artificial drying can best be summarized by considering it still to be in the experimental stage as regards the economic and management sides, though it is theoretically the ideal method of conservation. More information is still needed on the utility of dried grass as a feeding-stuff, though present indications are that it is a valuable food which fulfils expectations both in regard to composition and digestibility value, possessing special virtue in its relatively high carotene-content [18].

Present position of ensilage.—Considerable strides have been made in popularizing ensilage as a method of conservation and in the feeding of silage made from high-protein foods. Virtanen [19] has developed the A.I.V. process in which acid is added in amounts sufficient to bring the pH rapidly to below 4·0, and it has been widely applied in northern Europe for protein-rich crops.

Ensilage is also becoming everyday practice in Germany [20], where

grants are made towards the construction of silos. From the work at Jealott's Hill [21] the use of added molasses has been advocated as a more practicable process, giving results but little inferior to the A.I.V. process. The addition of 1 to 2 lb. of molasses, suitably diluted, to each 100 lb. of green crop, and the use of simple, cheap, wooden portable silos, has made the process easy and foolproof, and reduced the capital outlay to a negligible amount. The portable silo has the great advantage that it can be dismantled after the silage has settled, and be re-erected and refilled where it is needed. The resultant stack will dry out at the edge, and there will be some few inches of waste, but the material in the centre is far superior in feeding-value to stack silage. Two types of silage are made: a high-quality product in late May and autumn, containing 17–18 per cent. of crude protein in the dry matter, and a second quality with 13–15 per cent. of crude protein in the early weeks of June, both from surplus grass. In the United States of America very large amounts of silage are being made most successfully from grassland herbage and lucerne, with added molasses [22]. The advantage of such material over maize is fully realized and extensively exploited.

At Jealott's Hill we have also added mineral matter to the silage with complete success, and put forward this process as the most efficient way of feeding mineral matter directly. It will dissolve in the silage juices, and can easily be fed out. Phosphate-deficiency can be cured by adding mono-ammonium phosphate, calcium by adding calcium chloride, calcium and phosphate by adding superphosphate. Then, too, minor-element deficiencies are as easily cured; cobalt can be added with great ease and distributed evenly by diluting and adding with the molasses. There is no end to the possibilities of silage in this direction; every deficiency can be obviated or rectified by the use of silage reinforced with the appropriate chemical compound. All that is necessary is to use a compound which is neutral or acid in solution, since it will not then upset the acid formation in the silo.

Ensilage has another virtue: it can be used for improving the management of grassland by allowing all surplus grass to be removed when best for the sward.

It has also been suggested that silage can be made from bracken in districts where this material is becoming a pest. Maksimoff [23] has shown that silage made from young bracken has a high protein-content and is eaten without harm by all farm stock.

We have recently ensiled bracken at Jealott's Hill with every apparent sign of success. The produce was, however, of low digestibility, and although there was 14·98 per cent. of crude protein in the dry matter, its digestibility was only 5 per cent. This was possibly due to the high temperature that developed, as it proved difficult to pack. Some chaffed material still remains to be examined. The starch-equivalent value was only 11·2 lb. per 100 lb. of dry matter. The bracken was cut after the fronds had opened out, and it needed very careful packing to prevent mould-growth. Better results may be obtainable with heavy tramping and better weighting down. The silage was fed to some yearlings for over a month at the rate of 15 lb. per head daily without any harm. More

work is necessary before a final statement can be made on the possibilities of silage made from bracken. Cutting at a still earlier stage will have to be examined, but the fact that ensiled bracken has some feeding-value suggests that its production would help to compensate for the cost of eradication by cutting.

From this brief review of the present position of methods used in conserving fodder crops, the following appear to be the chief desiderata:

1. Haymaking methods should be improved as far as possible, in order to reduce the inherently large losses.

2. Silage should be made, wherever possible, from the better-quality material offering at times which are unsuitable for making hay. Ensiling is really complementary to haymaking, for it should provide a fodder with a dry matter of much higher feeding-value than hay. It can also be made a useful vehicle for adding mineral matter to the rations of farm stock, and it is of value in improving grassland by allowing the removal of all surplus growth before the sward deteriorates.

3. The ideal process is artificial drying, the general economic application of which should be the final aim of conservation.

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THE RESPONSE OF GRASSES AND CLOVER TO TREATMENT ON ACIDIC UPLAND SOILS, AND THE EFFECT OF HERBAGE PLANTS ON THE REACTION OF ACIDIC SOILS

Pt. IV. THE RESIDUAL EFFECTS OF TREATMENT ON *MOLINIA* AND FESCUE SOILS

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Two important matters regarding any treatment designed to improve a pasture are the immediate response and the durability of the effect. An early response to treatment ensures a return to the farmer in a reasonable period, and lessens the losses of manurial constituents which inevitably occur with the progress of time. The response of upland herbage in the years immediately following treatment has already been dealt with [1]. It has been shown that a combined treatment including cultivation, manuring, and seeding of cultivated grasses and clover is immediate in its effect. The importance of the joint action of the three treatments in bringing about this rapid and profound change in the herbage has been emphasized. Although great changes can be effected in these upland swards without cultivation by liberal manuring and controlled grazing [2], such changes are gradual, and require several growing-seasons and a number of manurial dressings before they become marked. When, however, cultivation is resorted to side by side with the sowing of manures and seeds, a much greater and richer herbage growth is immediately obtained. The prominent part played in these changes from the very commencement by wild white clover is remarkable in these areas, where the plant was previously non-existent. The cultivation and manuring bring about a very rapid multiplication of the nodule organisms, and transform these soils into an exceptionally favourable environment for the clover.

A matter of equal importance regarding the treatment of upland areas is the extent to which the treatment continues to influence productivity and the nutritive value of the herbage after the lapse of a number of years. One important factor which must influence the duration of the treatment is the rate at which the manurial constituents are leached from the soil, a high rate of leaching coinciding with a short period of effectiveness. This, however, is not the only factor which determines the period over which the herbage shows response to treatment. The capacity of the herbage to utilize manurial ingredients as well as the actual manurial content of the soil is of the greatest importance. This is especially true where the nature of the herbage has been radically altered, as in these experiments on upland swards, and where it is pos-

sible that the cultivated plants possess a greater root-range which enables them to utilize a soil solution beyond the reach of the native herbage.

The effect of a treatment designed to improve pasture productivity can be said to last so long as the herbage continues to yield a greater quantity of valuable constituents than the native sward, and it is proposed here to compare the treated herbage and the native sward over a period of seven years. These experiments were commenced in 1931, and no phosphatic manures were applied to the plots apart from the initial dressing of 12 cwt. per acre basic slag (15 per cent. P_2O_5) applied in the spring of that year. Table 1 shows the effect of the basic slag on the yield of dry matter for seven successive years.

TABLE 1. *Effect of Basic Slag during Successive Years on Yield of Dry Matter from New (sown) Herbage on* Molinia *and Fescue Areas (gm. per plot)*

	Molinia area			*Fescue area*		
Season	*Control plots (K)*	*Slag plots (P)*	*Gain in weight (P–K)*	*Control plots (K)*	*Slag plots (P)*	*Gain in weight (P–K)*
1931	23	103	80	15	138	123
1932	331	1,162	831	384	1,025	641
1933	335	740	405	499	773	274
1934	107	241	134	213	292	79
1935	190	413	223	274	472	198
1936	128	282	154	245	358	113
1937	126	269	143	289	396	107
Total	1,240	3,210	1,970	1,919	3,454	1,535

The above table shows that although the greatest response to treatment was obtained in both the *Molinia* and fescue area during the second and third season following the manurial treatment, a marked response has been maintained up to the seventh season. The mean increased weight for the *Molinia* area during the seven years amounts to 281 gm., as compared with a mean increased weight of 219 gm. for the fescue area. If we subject the increased weights obtained in the two areas to statistical treatment we find that t (3) is 2·17, showing that the difference between the response of the *Molinia* and fescue areas over the whole period is below the level of significance. If, however, we compare the response for the last four years we get a mean annual gain of 164 gm. in the *Molinia* area compared with a mean annual gain of 124 gm. in the fescue. The data over this period give a value of 6·31 for t, showing that the difference in response given by the two areas is highly significant for the last four years.

When limestone is applied in conjunction with basic slag the effect is greater over successive years than when slag alone is applied. This is seen from Table 2, where the yields obtained by applying 20 cwt. of limestone in conjunction with slag are compared with those derived from the control plots.

Over the whole experimental period the *Molinia* area does not give a

significantly greater response than the fescue to a joint application of basic slag and limestone ($t \rightarrow 1{\cdot}93$). The difference in response between the two areas over the last four years is, however, significant ($t \rightarrow 4{\cdot}44$).

TABLE 2. *Joint Effect of Basic Slag and Limestone during Successive Years on Yield of Dry Matter from New (sown) Herbage on* Molinia *and Fescue Areas (gm. per plot)*

	Molinia area			*Fescue area*		
Season	*Control plots (K)*	*Slag and limestone plots (C)*	*Gain in weight (C–K)*	*Control plots (K)*	*Slag and limestone plots (C)*	*Gain in weight (C–K)*
1931	23	268	245	15	432	417
1932	331	1,472	1,141	384	1,573	1,189
1933	335	884	549	499	760	261
1934	107	340	233	213	313	100
1935	190	715	525	274	435	161
1936	128	437	309	245	376	131
1937	126	446	320	289	396	107
Total	1,240	4,562	3,322	1,919	4,285	2,366

The response of the two areas to basic slag, and also to a joint application of slag and limestone, is shown graphically in Fig. 1, from which (1*a*) it is seen that the difference in response between the two areas, although small in magnitude, is remarkably constant during the latter part of the period under review. For the last five years the difference in response between the two areas as a result of the joint application of limestone and slag (1*b*) is greater than that resulting from the application of slag alone (1*a*). A comparison of (1*a*) with (1*b*) shows that in the fescue area the yield of dry matter is practically the same for the last five years with and without the application of limestone, and in the *Molinia* area during this latter period the influence of the limestone is evident.

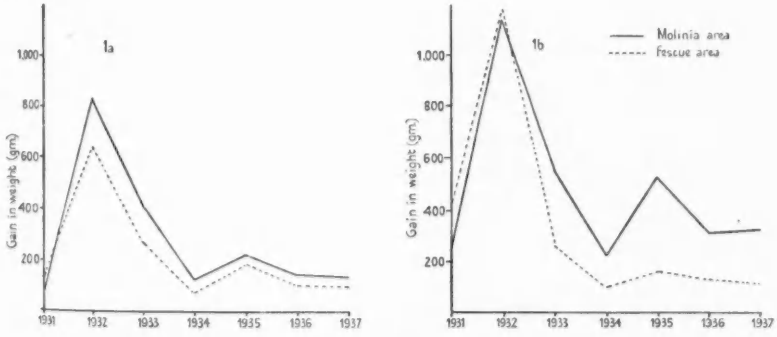

FIG. 1. Gain in dry matter (gm. per plot) over successive years from *Molinia* and fescue areas resulting from initial application of—

1*a*. basic slag

1*b*. basic slag and limestone

The Effect of Treatment on the Lime Yields of Herbage over Successive Years

One fact brought out by these experiments is the pronounced effect which basic slag immediately produces on the lime-content of the herbage. Table 3 clearly shows that although this effect is immediate, it is by no means transitory, but continues over many harvest years in spite of the heavy leaching of lime to which these soils are subject.

TABLE 3. *Effect of Basic Slag on Yield of Lime* (CaO) *from New* (*sown*) *Herbage on* Molinia *and Fescue Areas* (*mg. per plot*)

	Molinia area			*Fescue area*		
Season	*Control plots* (*K*)	*Slag plots* (*P*)	*Gain in lime yield* (*P–K*)	*Control plots* (*K*)	*Slag plots* (*P*)	*Gain in lime yield* (*P–K*)
1931	103	889	786	119	569	450
1932	1,247	9,121	7,874	1,505	8,697	7,192
1933	1,625	5,980	4,355	2,066	6,325	4,259
1934	745	2,012	1,267	1,319	2,550	1,231
1935	1,008	4,330	3,322	1,424	4,309	2,885
1936	1,320	2,560	1,240	1,660	3,050	1,390
1937	680	2,090	1,410	1,490	2,740	1,250
Total	6,728	26,982	20,254	9,683	28,340	18,657

The table shows that basic slag has a very similar effect on the yield of lime in both areas, and that the effect is as persistent on the lime yield as on the yield of dry matter. Although the lime yield of the herbage has been increased threefold in the *Molinia* and fescue areas, the lime needed for this improvement amounted to only 8·6 per cent. of the total lime in the slag. In spite of the marked improvement in the sward only a very small proportion of the lime in the slag was utilized for this improvement, and, as indicated later, this proportion was much lower than that of the total phosphate in the slag recovered in the herbage. It will be seen from Table 4 that the limestone supplement in the manure

TABLE 4. *Joint Effect of Basic Slag and Limestone on the Lime* (CaO) *Yield from New* (*sown*) *Herbage on* Molinia *and Fescue Areas* (*mg. per plot*)

	Molinia area			*Fescue area*		
Season	*Control plots* (*K*)	*Slag and limestone plots* (*C*)	*Gain in lime yield* (*C–K*)	*Control plots* (*K*)	*Slag and limestone plots* (*C*)	*Gain in lime yield* (*C–K*)
1931	103	4,620	4,517	119	5,691	5,572
1932	1,247	18,835	17,588	1,505	18,325	16,820
1933	1,625	8,143	6,518	2,066	6,025	3,959
1934	745	3,235	2,490	1,319	2,940	1,621
1935	1,008	8,253	7,245	1,424	4,340	2,916
1936	1,320	3,950	2,630	1,660	3,350	1,690
1937	680	4,070	3,390	1,490	3,440	1,950
Total	6,728	51,106	44,378	9,583	44,111	34,528

produced a further marked gain in the lime yield of the herbage, and this seems to indicate that the lime in the basic slag is not in a very readily available form. In Table 4 the joint effect of basic slag and limestone on the lime yield of the herbage is given.

The total gain in the lime yield of the herbage for the whole period of seven years has been more than doubled as a result of including limestone in the initial dressing for the *Molinia* area. An increase of 44,378 mg. was obtained where limestone was included, as compared with 20,254 mg. where basic slag only was applied. A very significant result has also followed the application of the limestone in the fescue area; its effectiveness is similar in both areas during the first two years, but the greater effect on the produce of the *Molinia* area is evident in subsequent periods. The data also indicate that the influence of the limestone is of longer duration on the *Molinia* than on the fescue area.

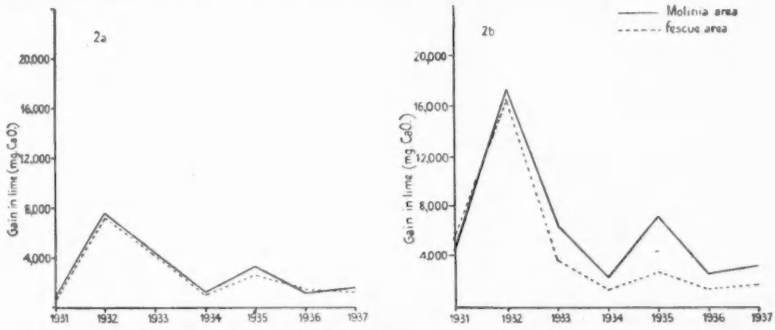

FIG. 2. Gain in lime of herbage (mg. CaO per plot) over successive years from *Molinia* and fescue areas resulting from initial application of—

2*a*. basic slag

2*b*. basic slag and limestone

Fig. 2 shows the gain in lime yield effected in the herbage as a result of basic slag alone (2*a*), and as a result of the joint action of limestone and basic slag (2*b*). From this it is clear that the effect of the slag alone is very similar on the produce of the two areas, but that during the last five years of the period under review the joint dressing of limestone and slag has been more effective on the *Molinia* area.

The Effect of Treatment on the Phosphate Yield of Herbage over Successive Years

A question of equal importance to that of the lime yielded by the herbage is that of its phosphate yield. Owing to the restricted world-supplies of phosphorus the significance of any factors which tend to increase and prolong the phosphorus gained by the herbage cannot be over-emphasized. Table 5 indicates the phosphate yielded by the control plots and that derived from the plots supplied with basic slag.

Table 5 shows that the gain in weight of phosphate resulting from the application of basic slag is somewhat similar in the two areas. Although

the gain in weight of phosphate is less than that obtained in the lime of the herbage (Table 3), a much greater proportion of the manurial phosphate than of the manurial lime has been recovered in the sward. Thus the total recovery of phosphate obtained in the herbage of the *Molinia* area for the seven years amounted to 19·5 per cent. of that applied as manure. In the fescue area this amounted to 18·1 per cent. Table 6 shows how these gains in phosphate yield are influenced by the application of limestone in conjunction with basic slag.

TABLE 5. *Effect of Basic Slag on the Yield of Phosphate* (P_2O_5) *from New (sown) Herbage on* Molinia *and Fescue Areas (mg. per plot)*

	Molinia area			*Fescue area*		
Season	*Control plots (K)*	*Slag plots (P)*	*Gain in phosphate yield (P–K)*	*Control plots (K)*	*Slag plots (P)*	*Gain in phosphate yield (P–K)*
1931	56	625	569	..	1,188	1,188
1932	856	8,023	7,167	1,037	7,251	6,214
1933	1,151	3,848	2,697	1,292	3,496	2,204
1934	243	1,050	807	501	1,252	751
1935	561	2,238	1,677	796	2,355	1,559
1936	415	1,490	1,075	974	1,881	907
1937	390	1,165	775	782	1,702	920
Total	3,672	18,439	14,767	5,382	19,125	13,743

The addition of limestone has raised the recovery of phosphate in the herbage over the whole period under review to 30·2 per cent. in the *Molinia* area, and to 24·2 per cent. in the fescue area. The remarkable effectiveness of limestone in raising the phosphate recovery on these acidic soils and thus lowering the losses in the most essential and expensive constituent reveals its importance in any system of manuring for these areas. Fig. 3 shows the gain in phosphate yield from the herbage as a result of applying basic slag alone (3*a*), and limestone in conjunction with basic slag (3*b*). From this it is clear that although the influence of

TABLE 6. *Joint Effect of Basic Slag and Limestone on Yield of Phosphate* (P_2O_5) *from New (sown) Herbage on* Molinia *and Fescue Areas (mg. per plot)*

	Molinia area			*Fescue area*		
Season	*Control plots (K)*	*Slag and limestone plots (C)*	*Gain in phosphate yield (C–K)*	*Control plots (K)*	*Slag and limestone plots (C)*	*Gain in phosphate yield (C–K)*
1931	56	2,163	2,107	..	3,518	3,518
1932	856	11,114	10,258	1,037	9,804	8,767
1933	1,151	4,287	3,136	1,292	3,414	2,122
1934	243	1,536	1,293	501	1,412	911
1935	561	3,652	3,091	796	2,126	1,330
1936	415	2,115	1,700	974	1,654	680
1937	390	1,697	1,307	782	1,629	847
Total	3,672	26,564	22,892	5,382	23,557	18,175

the limestone is limited to the first two seasons in the fescue area, the effectiveness has persisted in the *Molinia* area up to the last season.

It should be emphasized that the above data were obtained from plots where the herbage was continually removed while no addition was made to the soil to compensate for the nutrients taken away in the pasture cuts. The circumstances were therefore exceptional, and the losses much more severe than under grazing conditions. Another series of experimental plots was started at the same time as these enclosures [4], and whereas sheep were excluded from the latter they were allowed free

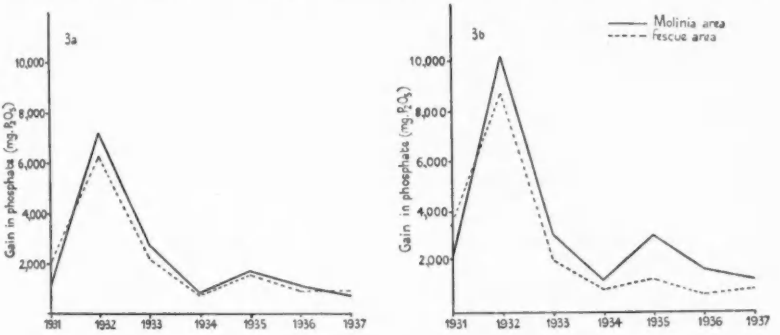

FIG. 3. Gain in phosphate of herbage (mg. P_2O_5 per plot) over successive years from *Molinia* and fescue areas resulting from initial application of—

3*a*. basic slag

3*b*. basic slag and limestone

access to the former. In some of these grazed experimental plots the manures used were similar to those adopted in the enclosed plots, and it was thought of interest to compare the annual gain on these plots with that obtained in the enclosures. Consequently, in 1934, cages were used for sampling and analysing these open-hill plots. As these plots produced herbage which was more nutritious than that on the untreated hill, the sheep concentrated on them to a marked extent. Table 7 gives an indication of the important increase in dry matter due to the manuring and consolidation effected by the sheep.

TABLE 7. *Gain in Dry-matter Yields obtained from Ungrazed and Grazed Plots as a Result of Initial Dressings of Basic Slag and Lime (per acre) in 1931*

Manuring	*Basic slag, 12 cwt.*		*Basic slag, 5 cwt.*		*Basic slag, 12 cwt. + Limestone, 1 ton*		*Limestone, 2 tons*	
Management	*No grazing*		*Free grazing*		*No grazing*		*Free grazing*	
Type	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*
Year								
1934	134	79	349	236	333	100	..	221
1935	223	198	170	258	525	161	88	442
1936	154	113	652	771	309	131	724	1,421
1937	143	107	582	897	320	107	880	1,751

The table shows that following the application of basic slag a much greater gain in dry-matter yield was obtained on the grazed than on the ungrazed plots, particularly in the sixth and seventh seasons after the application of the manures. The grazed plots show a better gain than the ungrazed, although basic slag was applied to the ungrazed plots at more than double the rate of that supplied to the grazed area, and this affords a clear indication of the way in which the sheep have contributed towards raising the productivity. It is seen that the effect of the limestone on the *Molinia* area was slow, and that it had no influence on the yield in 1934, and but little effect in 1935. In the following two seasons, however, its effect is very marked. On the fescue area the influence of the limestone has been more immediate, but in this area also its effectiveness has increased remarkably during 1936 and 1937. These phenomenal gains in dry-matter yield, which characterized all the grazed plots in 1936–7, are seen to stand in marked contrast to the somewhat diminished gains given by the ungrazed plots. In Table 8 the contribution made by the sheep towards the gain in lime yield of the herbage is shown.

TABLE 8. *Gain in Lime Yields obtained from Ungrazed and Grazed Plots as a Result of Initial Dressings of Basic Slag and Lime (per acre) in 1931*

Manuring	*Basic slag, 12 cwt.*		*Basic slag, 5 cwt.*		*Basic slag, 12 cwt. + Limestone, 1 ton*		*Limestone, 2 tons*	
Management	*No grazing*		*Free grazing*		*No grazing*		*Free grazing*	
Type	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*
Year								
1934	1,267	1,231	1,763	1,460	2,490	1,621	..	4,050
1935	3,322	2,885	1,508	1,600	7,245	2,916	1,152	3,736
1936	1,240	1,390	3,120	4,330	2,630	1,690	5,660	10,190
1937	1,410	1,250	2,880	5,070	3,390	1,950	6,280	15,220

Thus a higher yield of lime followed grazing in the slagged plots during the last two seasons. This is also true of the limed *Molinia* plots. The superiority of the grazed fescue plots that had received limestone was evident throughout the four seasons. One noteworthy effect which follows grazing is that the relative responsiveness of the *Molinia* and fescue areas to manures has been reversed. In the ungrazed plots a greater responsiveness has been forthcoming from the *Molinia* area to the joint application of slag and limestone, and the *Molinia* area has given at least as good a response to slag alone as the fescue area. Where, however, the grazing animal has been allowed free access, the gains derived from the fescue area tend to be greater than those obtained from the *Molinia*. This difference between the two areas is very marked where limestone has been applied. The chief reason for this greater response of the grazed herbage on the fescue area is that sown species contributed more to the flora than they did on the *Molinia* area. Thus by 1938 the average percentage of sown grasses and wild white clover in the total herbage cut from the fescue strip was 33, and from the *Molinia*

only 19. In addition, the tendency of the sheep to prefer the drier fescue area also contributed towards the change in relative response given by the two areas. Table 9 shows the influence of the grazing animal on the gain in phosphate yield of the herbage.

TABLE 9. *Gain in Phosphate Yields obtained from Ungrazed and Grazed Plots as a Result of Initial Dressings of Basic Slag and Lime (per acre) in 1931*

Manuring	*Basic slag, 12 cwt.*		*Basic slag, 5 cwt.*		*Basic slag, 12 cwt. + Limestone, 1 ton*		*Limestone, 2 tons*	
Management	*No grazing*		*Free grazing*		*No grazing*		*Free grazing*	
Type	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*
Year								
1934	807	751	2,060	1,548	1,293	911	nil	1,714
1935	1,677	1,559	1,179	1,426	3,091	1,330	451	2,058
1936	1,075	907	3,025	3,085	1,700	680	2,975	5,668
1937	775	920	2,554	4,622	1,307	847	4,970	6,790

Where grazing has occurred the gain in phosphate yield, particularly after the application of limestone, is greater in the fescue than in the *Molinia* area, showing again the more pronounced effect of the grazing animal on the fescue area. Owing to their selection by the sheep, the grazed plots in both areas have been favoured with a liberal return of phosphate to the soil. This is evident from the fact that during the four seasons under review only 5·72 per cent. of the phosphate applied in the slag was recovered by the herbage of the ungrazed *Molinia* area, whereas the phosphate recovered from the grazed plots was equivalent to 27·94 per cent. of the phosphate applied.

The Effect of the Treatment upon the Botanical Composition

The duration of the effect of the cultivating, manuring, and seeding treatments upon the herbage of the enclosed plots is given in Table 10. The plots selected for the data in the table are those where phosphate, calcium, and soil from a clover field consisted of part of the manurial dressing, other plots being included for comparison. The full details of the manuring have already appeared in Part I of this series [1].

The data from the plots of Group I (manured native sward), with the exception of (T) where no manure was given, show that under the influence of slag wild white clover made a volunteer appearance, but only to a small extent. Where limestone was also added (I) clover not only appeared among the native herbage but formed a considerable proportion of the 'keep'. The addition of soil from a clover field did not result in any increase in the amount of clover relative to the remainder of the herbage. On the contrary, where such soil had been added the proportions of clover were somewhat lower, not only in this group of plots but also in the other groups under this treatment. No alteration from the native herbage occurred where no manures were given (T).

In 1931 some of the plots had been cultivated by thorough digging and were sown with a mixture of perennial rye-grass, cocksfoot, and

wild white clover at the rate of 40 lb. per acre. In the earlier years of the trial these three species, where sown, comprised almost the entire herbage, but the native hill species gradually returned to a varying degree as the years went on. Plot (L) in the table shows that by 1938 slag under these conditions resulted in only a slightly better botanical composition than slag with no cultivation or seeds (R). Where limestone had been included, however, the result for cocksfoot was strikingly different. Even after eight years the herbage of plots (E) and (F), where

TABLE 10. *The Botanical Composition of the Herbage under Certain Treatments in the Fescue Area and in the* Molinia *Area (in brackets). Average productivity marks based on a scale of 0–10 for two cuts in 1938*

Plot	*Treatment*	*Cocksfoot*	*Wild white clover*	*Crested dogstail*	*Birdsfoot trefoil*	*Other species* *
	I. Not cultivated and no seeds sown.					
T	None	– (–)	– (–)	– (–)	– (–)	10 (10)
R	Slag and nitro-chalk	– (–)	– (T)†	– (–)	T (–)	10 (10)
I	Slag, limestone, and nitro-chalk	– (–)	2½ (1½)	– (–)	– (–)	7½ (8½)
J	As I, but with soil from clover field	– (–)	2 (1)	– (–)	– (–)	8 (9)
	II. Cultivated and sown with grass and clover seeds.					
L	Slag and nitro-chalk	½ (T)	½ (1)	– (–)	– (–)	9 (9)
E	Slag, limestone, and nitro-chalk	6 (5½)	1 (½)	T (T)	1½ (T)	1½ (4)
F	As E, but with soil from clover field	5½ (2½)	½ (T)	½ (T)	½ (1½)	3 (6)
	III. As Group II, but with no artificial nitrogen.					
P	Slag	T (–)	½ (½)	– (–)	½ (T)	9 (9½)
C	Slag and limestone	1½ (½)	½ (½)	– (–)	1 (½)	7 (8½)
	IV. Cultivated and sown only with grasses.					
G	Slag, limestone, and nitro-chalk	6 (1½)	1 (1)	T (–)	T (T)	3 (7½)
H	As G, but with soil from clover field	6 (2)	½ (½)	T (½)	½ (½)	3 (6½)
	V. Cultivated and seeds sown but not manured.					
K	None	– (–)	– (–)	– (–)	– (–)	10 (10)
	VI. Cultivated but no seeds sown.					
Q	Slag and nitro-chalk	– (–)	1½ (1)	– (–)	T (T)	8½ (9)

* Chiefly fine-leaved fescue, *Agrostis* spp., heather and *Carex* spp.
† T = trace.

slag and limestone had been applied, consisted of 55 to 60 per cent. of cocksfoot on the fescue area, and the same is true for plot (E) on the *Molinia* area. The crested dogstail and birdsfoot trefoil had made a volunteer appearance; their presence was probably due to slight amounts of seed being included as a contamination in the original sowing. The perennial rye-grass sown with the cocksfoot and white clover had contributed to the herbage up to and including 1937, but its amount had decreased each year, and by 1938 only traces remained. The addition of artificial nitrogen to these plots has resulted in a marked encouragement of the cocksfoot, as is seen on comparing plots (E) and (F) with (P) and (C) from which nitrogen was withheld.

On the plots treated with slag and limestone, (G) and (H), which had been cultivated but sown only with the two grasses, it will be noted that whilst cocksfoot gave 60 per cent. of the produce in the fescue area,

white clover, crested dogstail, and birdsfoot trefoil had appeared voluntarily. The contribution of cocksfoot to the herbage of plots (F), (G), and (H) was far less in the *Molinia* than in the fescue area, although previous findings in this trial indicated a higher level in soil fertility than in the fescue area. It will be observed that the remaining data for both areas are very similar.

The effect of cultivating and of sowing the three constituents of the mixture without manures is shown by Plot (K). Here the seeds germinated, but the plants died out within one year and were rapidly replaced by the native species. In this connexion Thomas [4], recording results of investigations carried out on the Cahn Hill Improvement Scheme, mentions the impossibility of successfully establishing seedlings from introduced seed without the addition of phosphates and lime.

In the last place, Plot (Q), which was cultivated, slagged, but unsown, established a sward consisting first of all of the native hill species. Under the influence of slag, however, wild white clover and birdsfoot trefoil gained a footing.

The data as a whole indicate that even under artificial conditions where the grazing animal is excluded, valuable contributions will be made over a period of years by lowland grasses and wild white clover on exposed hill-land, provided that cultivation is supplemented by phosphate *and* lime. Even where no sowing was made, wild white clover made a volunteer appearance under the influence of these fertilizers and gradually increased its yield. Cocksfoot (S. 26, pedigree, indigenous) has withstood the exposure and soils naturally low in fertility to a far better extent than has perennial rye-grass, and the small quantities of crested dogstail are slowly increasing in bulk. It is known from a study of the adjacent grazed plots that the above treatments would have been still more productive had the herbage been under the influence of the grazing animal.

Summary and Conclusions

Data are given regarding the duration of the effects of cultivating, manuring, and seeding treatments upon the herbage of *Molinia* and fescue areas. Over a period of seven years the results indicate that even under exceptionally unfavourable conditions valuable contributions are made to these areas by lowland grasses and wild white clover, provided that cultivation is supplemented by phosphate and limestone. Even where no seed was sown, wild white clover made a volunteer appearance which was very marked under the joint influence of these two fertilizers. Of the sown cultivated grasses cocksfoot (S. 26) has been found to withstand the unfavourable conditions to a far better extent than perennial rye-grass, and the application of artificial nitrogen at the time of sowing greatly encouraged this species.

Over the whole experimental period no significant difference occurred between the response of the two enclosed areas to treatment, but the *Molinia* area gave a significantly greater response than the fescue during the last four years of the experiment.

The effect of basic slag on the lime yield of the herbage is evident

after many harvest years. Although the lime yield in the herbage over a period of seven years was increased threefold as a result of applying slag, only 8·6 per cent. of the total lime in the slag was utilized for this improvement. The inclusion of limestone in the manurial dressing effected a further marked gain in the herbage-lime, and the data indicate that the influence of limestone is of longer duration on the *Molinia* than on the fescue area.

A much greater proportion of the phosphorus than of the calcium of slag has been recovered in the sward. Over the period of seven years under review the total recovery of phosphate obtained in the herbage of the *Molinia* area amounted to 19·5 per cent. of that applied as manure, compared with 18·1 per cent. recovered in the fescue area. The addition of limestone raised this recovery of phosphate to 30·2 per cent. in the *Molinia* area, and 24·2 per cent. in the fescue area.

The plots subjected to treatment on the open hill show a much greater gain over the control plots than the plots treated in the ungrazed enclosures, and indicate how sheep, by concentrating on the treated plots, have raised the productivity. The relative response of the two areas to treatment on the open hill differed from that found in the enclosed areas. Whereas in the enclosed areas a greater response was derived from the *Molinia* area to the application of slag and limestone, on the open hill a greater response was obtained from the fescue area as a result of applying these manures. This was mainly because more sown species contributed to the flora of the open-hill fescue area than to that of the open-hill *Molinia* area, but partly to the preference shown by the sheep for the drier fescue plots.

Acknowledgements

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A LIVE-STOCK INDEX FOR THE FYLDE DISTRICT OF LANCASHIRE

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THIS paper is an attempt to put on as exact a basis as possible a difficult problem inherent in the agricultural geography of a grass and stock district. One of the objectives of the geographical analysis of such an area is to express quantitatively the stock-carrying capacity of its grazing. This involves, as a preliminary, the equation of different classes of stock in terms of a common denominator—in other words, the construction of a stock index whereby different classes of stock can be related to one another. It is with the construction of a stock index for a particular district, the Fylde, as a preliminary to calculating the stock-carrying capacity of the grazing of that district, that this paper deals.

The need of a live-stock index is well recognized. Agricultural economists in this country and in America [1] have employed an index in which one dairy cow equals seven sheep. Watson and More have constructed a more detailed index for stock grazing in summer on grass [2]. The basis of these indices is, in each case, the amount of food consumed by each class of animal. Food consumption provides the common denominator by means of which different classes of stock may be related to each other. It forms an obvious basis for a stock index.

From data on animal nutrition it is possible to calculate food requirements in terms of dry-matter, starch equivalent, and protein equivalent, given the live-weight of the animal and its production requirement—whether live-weight increase for growing and fattening beasts, milk production for cows, sows, and ewes in milk, work production for horses, or egg production for poultry.

A live-stock index may be constructed for general or for local application. There is so much variation according to breed that it is impossible to give more than an approximate figure for each class of animal that will be capable of *general* application. The average live-weight of a South Devon cow (1,450 lb.) is more than double that of a Dexter (650 lb.) [3], though there is not quite the same difference in food requirement. There is almost the same variation between a large lowland ewe and a small upland ewe (200 lb. and 110 lb. respectively) [4]. There are further variations according to systems of management, but it is unnecessary to elaborate further the approximations inherent in a general index, for they are well recognized. A live-stock index constructed for *local* application can be based specifically on the particular breeds kept and on the particular systems of management practised in the district, and can therefore be calculated much more closely. In what follows no attempt is made to construct a live-stock index capable of general application. All that is attempted is to formulate a local index for employment in the Fylde, a district in west Lancashire. It will be applied later to the 1934 returns of the Ministry of Agriculture for the twenty-four parishes which

comprise the district. The categories of stock employed are those of the Ministry's classification. As the returns apply to June 4, the age of stock and the system of management are taken as they are at that time of the year [5]. The index refers, therefore, specifically to early June and cannot without modification be held to apply to any other month.

The Farm Data

It is necessary first to specify live-weights, live-weight increases and milk, work and egg-production (where these apply) appropriate to early June for each class of stock kept in the Fylde. These are set out in Table 1, which has been constructed on the following evidence. The adult live-weights are the standard live-weights for the breeds [6] kept in the district, with the modifications suggested by the local experience of farmers and of stock auctioneers. The live-weights and live-weight increases of growing beasts are drawn from observational data of growth-rates (of breeds like those kept in the district) at ages calculated, from Fylde farm-survey data, to apply to the several classes of young stock in early June [7]. Live-weight increases of fattening stock at this time of the year have been obtained from farmers in the district. Milk production of suckling ewes and sows in milk has been estimated from observational data abroad, but adjustments have been made to accord with Fylde conditions. The average number of piglings per sow in the Fylde is $7\frac{1}{2}$ and of lambs per ewe $1\frac{1}{2}$: according to the Ministry's returns for the twenty-four parishes of the district, the ratio of ewes to sheep under one year (excluding ram lambs being reared for service) is 1 : 1·42, but the earliest fat lambs are ready by Easter and many have been sold by June 4. Milk production of cows and heifers in milk has been calculated from evidence set out in more detail below. The work required from farm horses in early June, prior to haymaking, consists merely of the relatively light work of potato cultivations. The estimate of egg production of hens in early June is based on data received from poultry farmers in the Fylde, checked against flock performance data from other districts. Thus, the table has been drawn up to apply specifically to Fylde conditions and to early June.

In view of the importance of the dairy herd in the total number of live-stock units (see Table 6), the evidence on which the calculations for cows and heifers in milk have been made is summarized below. The dairy herd consists entirely of Dairy Shorthorns, Irish Shorthorns, and Shorthorn-Ayrshire crosses, together with a few herds of British Friesians. The standard live-weight of an adult Dairy Shorthorn or British Friesian cow is 1,250 lb., but the Irish Shorthorns and Shorthorn-Ayrshire crosses have somewhat lighter weights. Some correction is necessary also, because the Ministry's returns, to which the index will later be applied, do not distinguish between cows and heifers in milk. A Dairy Shorthorn heifer in milk, beginning her first lactation at $2\frac{1}{2}$–3 years old, which farm surveys made by me have shown to be the practice in the Fylde, has a live-weight of 965–1,065 lb., or approximately 80 per cent. of her weight when mature. The proportion of heifers in milk in the total dairy herd on those Fylde farms included in the Lancashire

County Milk Recording Society's returns was 29·0 per cent. during the five years 1929–30 to 1933–4. If these corrections be made, then the average live-weight of all cows and heifers in milk in the Fylde becomes 1,175 lb. This figure has been confirmed by local stock auctioneers.

In order to estimate milk yield, two lines of evidence have been employed: firstly, the records of those Fylde farmers who are members of

TABLE 1. *Estimates of Live-weight, Live-weight Increase, and Milk Production*

	Total Live-weight lb.	*Live-weight increase lb. per day*	*Milk production galls. per day*
Cows and heifers in milk	1,175	..	2·00
Cows in calf	1,175	..	..
Bulls in service	1,120	1·25	..
Heifers in calf	950	0·58	..
Other cattle, over 2 years	900	1·5	..
Other cattle, 1 to 2 years	745	1·25	..
Other cattle, under 1 year	335	1·15	..
Breeding ewes	140	..	0·43
Rams in service	200	..	..
Other sheep, over 1 year:			
Suffolk ewe lambs	150	0·21	..
Other sheep, under 1 year:			
Lambs fattening	60	0·5	..
Farm horses	1,550	..	..
Stallions in service	1,900	..	..
Unbroken horses, over 1 year	1,120	0·5	..
Unbroken horses, under 1 year:			
Light	300	1·0	..
Heavy	400	1·0	..
Other horses	1,025	..	..
Breeding sows, suckling	420	..	0·75
Breeding sows, in pig	420	..	..
Boars in service	350	0·5	..
Other pigs, over 2 months	80	1·0	..
Other pigs, under 2 months	14	0·5	..
Flock cocks and cockerels	7	..	..
Laying hens and pullets	5·25	..	0·5 (egg)
Fowls, under 6 months	2·75	0·02	..
Geese	9	0·1	..
Turkeys	3	0·06	..

the Milk Recording Society, adjusted to fit the generality of farmers in the district, and, secondly, the monthly returns of some 200 producers. The average daily yield per cow in the milk-recorded herds was 2·58 galls. during the five years 1929–30 to 1933–4, assuming a lactation-period of 315 days and 10 lb. as the weight of a gallon. The average length of 336 complete lactations on five of these farms works out, however, at 327·7 days (excluding the first 4 days after calving) which, if adopted, would reduce the daily yield for the five years to 2·48 galls. This figure refers to cows only and requires some correction for heifers. Sanders [8] has worked out the milk yield of heifers and of 2nd, 3rd, 4th, and 5th

lactation cows as percentages of the mature yield, considering the 6th lactation as maturity, and I have worked out the distribution of 657 lactations of cows and heifers on Fylde farms (1st, 35·8; 2nd, 26·0; 3rd, 17·5; 4th, 10·4; 5th, 5·5; 6th and over, 4·9 per cent.). If these corrections be made, the average daily yield for all cows and heifers in milk becomes 2·37 galls. This refers to the milk from recorded farms alone. If the milk yield on the generality of Fylde farms as compared with the milk-recorded Fylde farms is in the same proportions as the milk yield on all farms in England and Wales as compared with the milk-recorded farms in England and Wales [9], then the average daily milk yield on the generality of Fylde farms becomes 2·04 galls. This is the first line of evidence. The second line of evidence permits a calculation to be made specifically for early June [10]. The monthly returns for 1934 of some 200 producers, covering half the total cow population of the district, have been examined. They refer to gallonage sold and to number of cows on the farm. This last item includes on some farms lying-off cows as well as those actually in milk, but on others it refers to cows (and heifers) in milk alone. If all were in milk the daily sales per cow as an average of May and June (which may be taken to refer to early June) would be 1·78 galls., but if a correction of 16·04 per cent. (the percentage of cows in calf but not in milk in the total dairy herd of the 24 parishes on June 4, 1934) be made for the lying-off cows, the average of May and June becomes 2·12 galls. In what follows a daily yield of 2·0 galls. will be employed.

The Live-stock Index

Having stated these particulars of live-weight, live-weight increase and production, it is now possible to calculate maintenance and production requirements in terms of dry matter, starch equivalent, and protein equivalent. These supply the common denominator, by means of which the food requirements of different classes of stock can be compared. The total food requirements are set out in Table 2.

The standards employed require a little explanation. For cattle maintenance, the standards of Halnan [11] have been employed rather than those of the Departmental Committee on the Rationing of Dairy Cows, because they are closer to the strict requirements, irrespective of an allowance for 'normal movement'. Had it been possible, it would have been better to have included an allowance for normal movement for all classes of stock, as the calculations refer to summer grazing conditions, but, as data on this point exist for only a few classes of stock, the comparability of the calculations for all would thereby have been destroyed. For the same reasons, Wood's standards for milk production [12] have been used rather than those of the Departmental Committee. For live-weight increase of cattle the standards of Wood and Woodman [13] and of Watson and More [14] have been employed: they agree for growth without fattening and, although they differ in the values attributed to the early and later stages of fattening, they coincide for the middle stages. For sheep, there is so much divergence between Wood and Woodman [15] on the one hand, and Watson and his collaborators [16] on the other hand, that both sets of standards have been

incorporated in the table. Aberystwyth [17] and Scottish [18] experiments, and recent work at Cambridge [19] appear to confirm the dry-matter standards of Scott Watson and collaborators, and Mercer [20] advances reasons to indicate that the starch-equivalent standard for a

TABLE 2. *Total Food Requirements*

(*In lb. per day*)

	Dry matter		*Starch equiv.*		*Protein equiv.*	
Cows and heifers in milk	24·25		10·12		1·80	
Cows in calf	24·25		10·12		1·80	
Bulls in service	23·50		8·23		1·10	
Heifers in calf	21·25		7·24		1·05	
Other cattle, over 2 years	20·50		8·33		1·10	
Other cattle, 1 to 2 years	18·30		6·83		0·87	
Other cattle, under 1 year	8·75		4·42		0·66	
	(1)	(2)	(1)	(2)	(1)	(2)
Breeding ewes	4·29	3·57	2·86	..	0·51	..
Rams in service	5·29	4·40	2·00	1·35	0·11	0·14
Other sheep, over 1 year	4·50	3·75	2·34	1·66	0·25	0·19
Other sheep, under 1 year	2·43	2·02	1·64	1·35	0·21	0·27
Ewes with lambs (1·42 lambs to 1 ewe)	6·66	5·36	4·04	(3·63)	0·52	(0·60)
Farm horses	22·40		10·52		1·35	
Stallions in service	18·50		8·00		1·02	
Unbroken horses, over 1 year	13·00		5·25		0·81	
Unbroken horses, under 1 year:						
Light	5·50		3·05		0·75	
Heavy	6·50		3·42		0·80	
Other horses	18·25		8·50		1·20	
Breeding sows, suckling, including unweaned pigs	9·25		7·65		1·63	
Breeding sows, in pig	9·25		3·15		0·60	
Boars in service	8·25		4·00		0·70	
Other pigs, over 2 months	3·15		2·23		0·45	
Flock cocks and cockerels	0·217		0·165		0·023	
Laying hens and pullets	0·217		0·186		0·034	
Fowls, under 6 months	0·185		0·149		0·024	
Ducks, over 6 months	0·353		0·269		0·054	
Ducks, under 6 months	0·176		0·135		0·027	
Geese	0·269		0·162		0·034	
Turkeys	0·204		0·168		0·029	

(1) According to the standards of T. B. Wood and H. E. Woodman.
(2) According to the standards of J. A. S. Watson, D. Skilbeck, and J. C. B. Ellis; J. A. S. Watson and J. A. More.

ewe's milk production specified by Wood and Woodman is too low. For horses, Wood's standards have been adopted [21]. For pigs, the standards in Rations for Live Stock and those of the Harper Adams' experiments [22] have been employed, and these, translated into terms of meal, are generally followed in Lancashire [23]. The standards used for fowls are those of Halnan [24], and for geese, ducks, and turkeys, those of the National Institute of Poultry Husbandry.

It is now possible to construct the live-stock index. The total food

requirements (but excluding an allowance for normal movement) of a cow in milk, with a live-weight of 10½ cwt. and a daily milk yield in early June of 2 galls., have been taken as the unit. The index is set out in Table 3. It will immediately be noticed, however, that the index differs

TABLE 3. *The Live-stock Index*

	Dry matter		*Starch equiv.*		*Protein equiv.*	
Cows and heifers in milk	1·0		1·0		1·0	
Cows in calf	1·0		1·0		1·0	
Bulls in service	0·97		0·81		0·61	
Heifers in calf	0·88		0·72		0·58	
Other cattle, over 2 years	0·85		0·82		0·61	
Other cattle, 1 to 2 years	0·75		0·67		0·48	
Other cattle, under 1 year	0·36		0·44		0·37	
	(1)	(2)	(1)	(2)	(1)	(2)
Breeding ewes	0·18	0·15	0·28	..	0·28	..
Rams in service	0·22	0·18	0·20	0·13	0·06	0·08
Other sheep, over 1 year	0·19	0·15	0·23	0·16	0·14	0·10
Other sheep, under 1 year	0·10	0·08	0·16	0·13	0·12	0·15
Ewes with lambs (1·42 lambs to 1 ewe)	0·27	0·22	0·40	(0·36)	0·29	(0·33)
Farm horses	0·92		1·04		0·75	
Stallions in service	0·76		0·79		0·57	
Unbroken horses, over 1 year	0·54		0·52		0·45	
Unbroken horses, under 1 year:						
Light	0·23		0·30		0·42	
Heavy	0·27		0·34		0·44	
Other horses	0·75		0·84		0·67	
Breeding sows, suckling, including unweaned pigs	0·38		0·76		0·91	
Breeding sows, in pig	0·38		0·31		0·33	
Boars in service	0·34		0·40		0·39	
Other pigs, over 2 months	0·13		0·22		0·25	
Flock cocks and cockerels	0·009		0·016		0·013	
Laying hens and pullets	0·009		0·018		0·019	
Fowls, under 6 months	0·008		0·015		0·013	
Ducks, over 6 months	0·015		0·027		0·030	
Ducks, under 6 months	0·007		0·013		0·015	
Geese	0·011		0·016		0·019	
Turkeys	0·008		0·017		0·016	

(1) According to the standards of T. B. Wood and H. E. Woodman.
(2) According to the standards of J. A. S. Watson, D. Skilbeck, and J. C. B. Ellis; J. A. S. Watson and J. A. More.

very considerably according as it refers to dry matter, to starch equivalent, or to protein equivalent, and that it is not possible from this table to give a single answer to any question relating to the equation of different classes of stock with each other.

The Grazing Index

The live-stock index thus constructed refers to *total* food requirements. Some of this food requirement is supplied by the animal's own grazing and some by the hand of the feeder. If an index is to be of value in grassland-stocking problems, it is that part of the total food

requirement supplied by grazing alone that is relevant. The proportion provided by grazing varies with the time of the year, with the kind of stock, with the quality of the grass, and with the system of management. Early June is close to the season of maximum growth of grass, and the proportion that grass bears to the total food consumption is near its maximum level. But not all classes of stock, for physiological reasons, can obtain their total food requirements from grass alone. It is necessary, therefore, to estimate the grass consumption of each class of stock at this time of the year under the management practised in the Fylde, and to construct a grazing index as distinct from the total food index so far considered. The grazing index will later be related to the acreage of grassland available for grazing in early June, and by this means the carrying capacity of the pastures at this time of the year will be calculated.

There is no doubt that it is possible for a 2-gallon cow on good grassland, such as that of the Fylde, and on June 4, early in the grazing season, to obtain her total food requirements from grass alone [25]. If the composition of early June grass be placed at 20 per cent. dry matter, 12 per cent. starch equivalent, and 2·5 per cent. protein equivalent [26], and if an allowance of 1 lb. starch equivalent be made for energy expended in grazing June pastures, the total daily food requirement would be met by grass containing 18·54 lb. dry matter, 11·12 lb. starch equivalent, and 2·32 lb. protein equivalent. This is well within the limit of the cow's appetite, and in fact provides more protein than is strictly necessary. The Fylde is, however, heavily stocked, and foods are fed in May and June as well as in winter. Many farmers feed a little, if for no other reason than to keep cows quiet while they are being milked. Feeding in May and June is also a little higher than it would otherwise be, as some grass is saved for July. I have calculated the approximate level of feeding of dairy stock in May and June (the mean of which may be taken to refer to June 4) from two sources of evidence: firstly, from farm records giving individual practice, and secondly, from the records of firms selling foods in the Fylde giving the generalized practice in the Fylde as a whole. Of a random sample of ten farms from which information has been obtained, three feed very little or not at all in early June, two feed about one-third of the production requirement, two about two-thirds, and three between two-thirds and a full production ration. If these farms provide a true sample of practice in the Fylde, then about half of the production requirement is fed at this time of the year. It is clear, however, that there is great variation, depending on density of stocking, level of milk yield, and quality of grass, as well as on personal differences of management. Some, as Orr's records show [27], feed more heavily than is necessary. In pursuit of the second line of evidence, I have obtained returns from four firms of the proportions which their monthly sales in the Fylde for each of the months of 1934 bore to their total for that year. The sales in May and June (the mean for the two months), expressed as a percentage of the sales during November–March, months of winter feeding, were 64·1, 86·5, 88·5, and 95·4 per cent. respectively. The level of milk sales in May–June was 18·8 per

cent. higher in 1934 than in November–March, according to the returns of the large sample of producers quoted above (p. 66). The sales-returns of the first alone of these firms, however, refer only to foodstuffs for dairy cows, the others incorporating also foods fed to other stock including poultry. Where the foods sold consist of grain or millers' offals, it is not possible to state categorically to what class of stock they are fed on the farm. With some firms the quantities of poultry food sold—the Fylde is one of the most densely populated poultry districts in the country—are almost as high as the quantities of cattle food, and in early June, near the time of maximum egg production, the level of poultry feeding is undoubtedly higher than in winter. The returns from the first firm alone can, therefore, be employed here. There is not space to give the calculation stage by stage, but the conclusion is that purchased feed in May–June is sufficient for the production of 1·02 galls. of milk daily, i.e. half of the previously calculated May–June production of 2·0 galls. Both lines of evidence thus give a similar result. If this purchased feed is supplied in the form of a grass nut, grazing then supplies 14·56 lb. dry matter, 8·72 lb. starch equivalent, and 1·82 lb. protein equivalent.

The data on the grass consumption of sheep have been taken from experiments at Aberystwyth [28] and at Jealott's Hill [29], and on the grass consumption of in-pig sows from the Cambridge experiments [30]. The farm horses at grass obtain their maintenance requirements from grazing and are fed provender for any light work, such as potato cultivations, they may be called upon to perform. It has been estimated that when at grass they have maintenance requirements somewhat similar to cattle of similar weight [31]. The unbroken horses, over a year old, and about a quarter of the foals (the rest of the foals are still running with the mares) obtain their total requirements from grass. Of the poultry, only the geese and goslings consume appreciable quantities of grass at this time of the year. Stallions, bulls, and rams in service have been excluded from the grazing index, as in practice they are fed most, if not all, of their food requirements. Harness horses and vanners, the 'other horses' of the Ministry's returns, have also been excluded on the ground that, being more continuously in work than the farm horses at this time of the year, they are also fed most of their requirements.

These estimates of grass consumption are set out in Table 4. They are based on the starch equivalent which it has been estimated that each class of animal obtains from grass, under the system of management practised in the Fylde and in early June. The construction of the table of pasture units by Watson and More follows the same method [32]. The content of this grass in dry matter and in protein equivalent as it is in early June, according to the formula employed on p. 69, has been calculated accordingly.

It is now possible to construct the grazing index. This is set out in Table 5. The requirements of a 2-gallon 10½ cwt. cow or heifer in milk obtaining her *total* requirements from grass have been taken as the unit, and the grass consumed by other classes of stock related to them. The Fylde cow, fed in part on foods other than grass, is thus less than a

grazing unit. Approximately 5 shearling sheep or $4\frac{1}{2}$ ewes, together with their lambs, are, as grazing units, equal to one cow in milk obtaining her total requirements from grazing. The local ratio of 5 sheep to 1 cow is less than the generalized ratio of 7 sheep to 1 cow quoted at the beginning of this article. Farm horses are just over two-thirds of a grazing unit, which is the value given to them as grazing units by Watson and More.

TABLE 4. *Grass Consumption*
(*In lb. per day*)

	Dry matter	*Starch equiv.*	*Protein equiv.*
Cows and heifers in milk	14·56	8·72	1·82
Cows in calf	14·56	8·72	1·82
Heifers in calf	13·73	8·24	1·72
Other cattle, over 2 years	13·88	8·33	1·73
Other cattle, 1 to 2 years	11·38	6·83	1·42
Other cattle, under 1 year	4·52	2·71	0·56
Ewes with lambs (1·42 lambs to 1 ewe)	4·00	2·40	0·50
Other sheep, over 1 year	3·50	2·10	0·44
Farm horses	13·33	8·00	1·67
Unbroken horses, over 1 year	12·97	7·78	1·62
Unbroken horses, under 1 year:			
Light	6·67	4·00	0·83
Heavy	9·17	5·50	1·15
Sows, in pig	3·00	1·80	0·38
Geese	0·27	0·16	0·03

TABLE 5. *The Grazing Index*

	Dry matter	*Starch equiv.*	*Protein equiv.*
Cows and heifers in milk	0·79	0·79	0·79
Cows in calf	0·79	0·79	0·79
Heifers in calf	0·74	0·74	0·74
Other cattle, over 2 years	0·75	0·75	0·75
Other cattle, 1 to 2 years	0·61	0·61	0·61
Other cattle, under 1 year	0·24	0·24	0·24
Ewes with lambs (1·42 lambs to 1 ewe)	0·22	0·22	0·22
Other sheep, over 1 year	0·19	0·19	0·19
Farm horses	0·72	0·72	0·72
Unbroken horses, over 1 year	0·70	0·70	0·70
Unbroken horses, under 1 year:			
Light	0·36	0·36	0·36
Heavy	0·49	0·49	0·49
Sows, in pig	0·16	0·16	0·16
Geese	0·015	0·015	0·015

Of in-pig sows, 6 are equal to 1 cow in milk, an in-pig sow consuming a little less grass than a shearling sheep. The grazing index is, however, applicable only to the Fylde, and only to the Fylde at the beginning of June.

The Stock-carrying Capacity

It is now possible to apply the grazing index to the actual numbers of stock and to the actual acreage of grazing as returned to the Ministry of Agriculture for June 4, 1934. The returns refer to the twenty-four

parishes of the Fylde, all of which have a comparable form of live-stock economy. The totals of these parishes for each class of stock as actually returned (with adjustments in order to eliminate the suckling sows and the young foals still with the mares) are set out in Col. 1 of Table 6. Col. 2 of the same table gives the grazing index number previously calculated for each class of stock, and Col. 3 the grazing units, which are obtained by multiplying the figures of Col. 1 and Col. 2.

TABLE 6. *The Grazing Units*

	Actual returns	*Grazing index*	*Grazing units*
Cows and heifers in milk	11,989	0·79	9,471·31
Cows in calf	2,290	0·79	1,809·10
Heifers in calf	1,087	0·74	804·38
Other cattle, over 2 years	1,580	0·75	1,185·00
Other cattle, 1 to 2 years	2,390	0·61	1,457·90
Other cattle, under 1 year	2,336	0·24	560·64
Total cattle units	..	..	15,288·33
Ewes with lambs (1·42 lambs to 1 ewe)	7,777	0·22	1,710·94
Other sheep, over 1 year	793	0·19	150·67
Total sheep units	..	..	1,861·61
Farm horses	1,252	0·72	901·44
Unbroken horses, under 1 year:			
Light	3	0·36	1·08
Heavy	16	0·49	7·84
Unbroken horses, over 1 year	146	0·70	102·20
Total horse units	..	..	1,012·56
Sows in pig	1,392	0·16	222·72
Geese	4,734	0·015	71·01
Total grazing units	..	..	18,456·23

The table of grazing units permits the carrying capacity of the pasture to be determined. At the time of the June returns the grazing is made up of permanent grass with some rough grazing and some pasture on rotation grass. It is too early in the year for meadow or rotation grass mown the same season to be available for grazing. In the same parishes for which grazing units have been calculated there are 21,168 acres of permanent grass not for hay, 739¼ acres of rough grazings, and 413½ acres of rotation grass not for hay, making a total of 22,320½ acres. From the acreage of permanent grass must be deducted the area that is appropriated by wired poultry-runs on which there is little grazing by general farm stock, so that it is largely withdrawn from the acreage available for grazing. It is possible to submit no more than an estimate of this area. It is estimated that 70 per cent. of the total number of fowls in the Fylde are kept in wired runs, and that the average density within these wired runs is 350 to the acre. There is thus obliterated 1,683¾ acres. It is possible that some of the grazing upon which fowls on free range are kept is also obliterated from the point of view of the grazing of farm stock, but

it is not possible to submit an estimate on this account. A deduction should also be made on account of ducks, which, if 100 are allowed to the acre, would amount to 176 acres. It is thus probable that some 1,860 acres should be deducted from the gross acreage of the pastures to obtain the net acreage which is available for the grazing of the classes of stock listed in Table 6. If these deductions are made the net acreage becomes 20,460½. There should also be some adjustment for the lower grazing quality of the rough grazings. If it be assumed that two acres of rough grazings—it is mostly marsh grazing in the Fylde—equal one acre of permanent grass and rotation grass, the net acreage becomes 20,091.

According to Table 6, the total number of grazing units is 18,456·23. The ratio is therefore 0·92 grazing unit per acre. The ratio of a cow to an acre is a common one for good grass on a clayey loam in a fairly wet western district, such as the Fylde. The ratio applies, however, only to the flush season of grass growth and does not indicate the carrying capacity for the whole of the summer grazing season. The ratio will be very much less later in the season, when the aftermath of the meadows (12,951¾ acres) is added to the area available for grazing and when, because of the greatly increased feeding of dairy stock and the sale off the farm of fat lambs and ewes, the total number of effective grazing units will be greatly diminished. The calculation of the carrying capacity for the whole of the grazing season presents, however, a number of additional problems and will not be attempted here.

I have been asked to state, in conclusion, the extent to which the number of grazing units calculated for local application by the methods adopted in this article differs from the number of units calculated from the generalized indices, if these were to be applied to the Fylde. Two such generalized indices will be considered. The first is the animal-unit index employed by Gray and, among others, by the Farm Economics Branch of the Cambridge School of Agriculture. This index refers to the total food consumed by each class of animal, irrespective of how it is provided. It is to be compared, therefore, with the live-stock index (Table 3) of this article rather than with the grazing index (Table 5). A cow is the unit of both indices. The starch-equivalent values of Table 3 are used in the comparison, and for sheep the lowest of the two values is employed. A few categories have been omitted where comparison is not possible. The total number of animal units, according to the index employed by Gray and others, is 26,561·1, and the total number of live-stock units, according to the live-stock index of this article, is 32,957·3, a difference of 19·4 per cent. The difference would be greater if cows, the unit of each index, did not play such a dominant part in the live-stock economy of the district. If these be eliminated as constants, the difference becomes one of 34·2 per cent. This comparison is based on the starch-equivalent values. If, however, the dry-matter values of Table 3 be employed in the comparison, the difference between the two indices is reduced to 5·1 per cent. and, if cows be eliminated as constants, to 10·4 per cent. If the protein-equivalent values of Table 3 be employed, the difference between the two indices is 17·5 per cent., and, if cows be eliminated as constants, 31·5 per cent.

The second is the pasture-unit index, constructed by Watson and More. This is more specific and more elaborately calculated. It is constructed on the same principles as the grazing index of this article, and it is with the grazing index rather than with the live-stock index that it is to be compared. The unit of the index is, in each case, a 10½-cwt. cow yielding 2 galls. of milk daily, and obtaining her total food requirements from grazing. Watson and More's pasture index gives particulars for several classes of cattle, sheep, and horses, but the specifications do not permit of comparison with all the categories included in the grazing index of this article. In respect of those categories for which comparison is possible, the total number of pasture units, according to Watson and More, is 22,044·2, and the total number of grazing units, according to the grazing index of this paper, is 18,153·5, a difference of 21·4 per cent. The difference is, however, due very largely to the allowance that I have made in the grazing index for foods additional to grass, an allowance which, of course, varies considerably from district to district.

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THE EFFECT OF SOME PLANT GROWTH-SUBSTANCES ON DRY-MATTER PRODUCTION IN PLANTS

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In view of the hormone theory of plant-growth and of the proved effects of certain natural and synthetic organic substances on cell-elongation, cambial activity, epinasty, root-stimulation, &c., it is pertinent to inquire whether organic matter added to the soil may affect growth by virtue of the growth-substance it contains. Various workers have described the effects upon plant-growth of organic materials of varying complexity and origin, and others have studied the localized effects of reasonably pure compounds, but little work has been done on the dry-matter production of *whole* plants when treated with these compounds. Experiments of this type were carried out at Jealott's Hill in 1936 and 1937, and are described in this paper, consideration being given only to pure synthetic growth-promoting substances, such as β-indolylacetic acid, α-naphthylacetic acid, skatole, and ascorbic acid.

Amongst the relevant papers on plant hormones is one by Hitchcock and Zimmerman [1], who found that synthetic growth-substance can be absorbed by the normal root-systems of plants.

Pearse [2] has reported the effect of phenylacetic acid and indolylbutyric acid upon the growth of tomato plants. Spraying with a 0·1 per cent. solution of either of these substances increased the height of the plants and the length of the internodes and petioles. Phenylacetic acid depressed the root- and leaf-growth, but increased the growth of stem and petiole; indolylbutyric acid depressed leaf-growth, but increased that of root, stem, and petiole. The water-content of plants sprayed with these substances was always higher than those sprayed with water only. The total dry weight of treated plants was usually lower than that of the controls, although the concentration could be lowered to reduce this difference to insignificance. In no instance was increased dry-matter production recorded. In a further communication Pearse [3] reported the effects of applying β-indolylacetic acid to broad-bean plants grown in water-cultures, the daily application being 1 c.c. of a 0·1 per cent. aqueous solution, by spraying, or by adding the same quantity to the culture itself. Each treatment reduced dry-matter production in the tops; the latter retarded the growth in length of the roots without altering the total root-weight, whilst spraying slightly decreased the dry weight of root without altering its form.

Marmer [4] has grown wheat seedlings in solutions containing chemical growth-substances, and found that although secondary root-growth is affected, the growth of coleoptile and first leaf are not stimulated by indolylacetic, indolylpropionic, and indolylbutyric acids, their effect being usually depressive.

On the other hand, Amlong and Naundorf [5] report that spraying plants with N/100 solutions of β-indolylacetic acid accelerated growth of vegetative and reproductive organs; and Loehwing and Bauguess [6] state that the addition of a dilute solution (1 in 15,000) of β-indolylacetic acid to the soil produces a transitory acceleration of growth in stock seedlings, this effect disappearing in ten days. Greenfield [7], also working with stock seedlings, likewise observed this effect.

Macht and Grumbein [8] have shown that brief exposure of *Lupinus albus* seedlings to weak solutions of β-indolylacetic, β-indolylbutyric, and α-naphthylacetic acids has stimulated root-length. Thimann [9] and Thimann and Lane [10] state that as a result of the root-stimulation of seedlings treated with dilute β-indolylacetic acid, the development of the shoot is often accelerated by such treatment, for water-supply is so important to the growth of the young plant. These authors further indicate that exposure to high concentrations (e.g. 200 mg. per litre) will depress root-growth, whilst lower concentrations (e.g. 0·032 mg. per litre) stimulate it. If such treated seedlings are rinsed and planted out, the shoot-growth of those treated with the lower concentrations immediately surpasses that of the controls, only to be surpassed subsequently by those treated with the higher strength.

Grace in several communications [11, 12, 13] has described a physiological growth-curve for plants treated with solutions of synthetic growth-substances of the types represented by indolyl- and naphthylacetic acids. He found that the higher concentrations are toxic, but the more dilute increase growth. Most recently [13], referring to growth of wheat plants after pretreatment of the seed with solutions of β-indolyl- and α-naphthylacetic acids of different concentrations, he reports that 'the dry weights of the plants of these two samples, grown in soil, fail to suggest appreciable increase from hormone treatment'.

In the first series of experiments carried out at Jealott's Hill, relatively high concentrations and large amounts of growth-substances were used, and these experiments are described here. β-indolylacetic acid and α-naphthylacetic acid (or their sodium salts) were used because they are amongst the most active of the synthetic materials, and several experiments were made with skatole and ascorbic acid for reasons given below. Glover [14] has reported that skatole produces curvature of the *Avena* coleoptile, and Warne and Jackson [15] that it stimulates the initiation of roots from stem-tissue. β-indolylacetic acid is present in animal urine and skatole in animal faeces; it is probable that both are to be found in farmyard manure.

Davies, Atkins, and Hudson [16, 17], Havas [18], Hausen [19, 20, 21], and Virtanen [22, 23] consider that ascorbic acid stimulates plant-growth, as measured by dry-matter production. Contrary to this, Clark [24] concludes that ascorbic acid is *not* a cell-elongating hormone, and does not facilitate the action of growth-promoting substances naturally present in the plant.

Avery, Burkholder and Creighton [25, 26] have shown that growth-substance capable of causing cell-elongation is scarcely detectable in plants grown without added nitrogen, and also, when the relative propor-

tions of certain anions and cations are considered, that growth-substance is most abundant in shoot-tips of plants grown with high concentrations of nitrogen. It was, therefore, thought desirable to determine the effect of applying growth-substances in solution to plants grown with either deficiency or sufficiency of nitrogen. Two experiments along these lines are reported.

Cholodny [27] has claimed that large increases in yield are obtained when seeds are kept for periods up to 48 hours in solutions of β-indolylacetic acid before planting out. Similar observations have been made by Amlong and Naundorf [5]. On the other hand, Davies, Atkins, and Hudson [16, 17] and Cajlachjan and Zdanova [28] have obtained no stimulating effect from soaking seeds of various species in solutions of β-indolylacetic acid. One trial is described which bears upon this aspect of the subject.

Experimental Methods

All experiments here recorded were pot-culture experiments carried out in glazed earthenware pots, with the usual precautions for reducing variability and ensuring uniform conditions. Plants were grown (unless otherwise stated) in well-washed Bedfordshire sand and watered through a central 'thumb' pot with rain-water. Each pot contained 26 lb. of sand.

The basic nutrient mixture applied to each pot was as under:

Disodium hydrogen phosphate ($Na_2HPO_4 \cdot 12H_2O$)	1·26 gm.
Sodium nitrate	4·55 ,,
Potassium sulphate	0·925 ,,
Calcium chloride ($CaCl_2 \cdot 6H_2O$)	0·185 ,,
Magnesium sulphate ($MgSO_4 \cdot 7H_2O$)	0·625 ,,
Ferric chloride ($FeCl_3 \cdot 6H_2O$)	0·05 ,,
Manganese sulphate ($MnSO_4 \cdot 7H_2O$)	0·01 ,,
Boric acid (H_3BO_3)	0·01 ,,

In all cases the fertilizers were applied in solution to the surface of the sand, gently watered in, and the foliage lightly syringed to remove stray drops. The number of doses and the intervals at which they were given are stated separately for each experiment. The β-indolylacetic acid and the α-naphthylacetic acid used were pure synthetic products. The ascorbic acid (l-ascorbic acid) and skatole were standard B.D.H. pure chemicals. All solutions were freshly prepared for use, the ascorbic acid in particular being made up immediately before application. All pots were replicated and arranged in randomized positions.

The plants were harvested and divided into roots and tops, and the roots washed as free as possible from sand before the dry matter was determined. Sometimes the roots appeared to be contaminated even after prolonged washing and in these cases the observations were discarded.

The analysis of variance was used to examine the dry-matter yields. Where germination-counts were undertaken the speed of germination was measured by the analysis of 'Rate Index', and the amount of germination by the analysis of 'Final Count', as proposed by Bartlett [29]. All significant differences mentioned are for $P = 0{\cdot}05$.

Experimental Results

Experiment 1.—In this experiment 40 seeds of white mustard (*Brassica alba*) were sown per pot on May 13, 1936. Two-fifths of the basal fertilizer mixture was given to each pot prior to sowing, and the remaining three-fifths in three equal amounts during the growth of the plants. After germination these were thinned, first to 20, and finally to 10 plants per pot. The β-indolylacetic acid, sodium β-indolylacetate, and ascorbic acid were applied as freshly prepared aqueous solutions to the surface of the sand in the pots. The three doses were given at weekly intervals on June 4, 11, and 18. Table 1 gives the amounts and concentrations of the substances used, and the experimental results. There were 9 pots for each treatment and harvesting took place on June 25.

TABLE 1. *Experiment I: Treatments and Results*

Treatments	*Total application per pot*	*Mean dry weight of tops, gm. per pot*
1. Control	..	11·0
2. Control	..	
3. β-indolylacetic acid (0·0033% soln.)	10 mg.	11·2
4. „ „ (0·0165% „)	50 „	10·4
5. Sodium β-indolylacetate (0·0037% soln.)	≡10 „ acid	10·9
6. „ „ (0·0185% „)	≡50 „ „	*10·2*
7. Ascorbic acid (0·0033% soln.)	10 „	11·1
8. „ „ (0·0165% „)	50 „	*10·1*
Standard error		0·32
Significant difference A (to compare any treatments)		0·90
„ „ B („ control and any treatment)		0·80

Significant differences from the control are given in italics.

No account was taken of the dry weights of the roots, because difficulty was experienced in trying to remove the last traces of sand.

The only significant results in this experiment are the depressions in yield when the highest levels of sodium β-indolylacetate and ascorbic acid were used.

Experiment 2.—Owing to the lateness of the season, and in the hope that a ripe crop would be harvested, bere[1] (kindly provided by Mr. W. M. Findlay, of the North of Scotland College of Agriculture, Aberdeen) was sown at the rate of 16 seeds per pot on July 24, 1936, after the basal fertilizer mixture had been applied. Plants were thinned to leave 4 plants per pot, and the solutions of growth-substance were given in eight equal doses on July 24, 31, August 7, 14, 21, 28, September 10 and 17. There were 6 replicate pots for each treatment.

Daily germination-counts and periodic height-measurements and

[1] Bere (*Hordeum vulgare*) is a four-rowed barley, which on account of its rapid growth, is one of the most suitable cereals for the northern parts of Europe, where the summers are short.

tiller-counts were made during the experiment; none of these showed any significant differences and are, therefore, not included.

The crop was harvested green on September 22, 1936; treatments and results are given in Table 2.

TABLE 2. *Experiment II: Treatments and Results*

Treatments	Total application, mg. per pot	Mean dry weight, gm. per pot	
		Tops	Roots
1. Control	..	8·35	4·85
2. Control	..		
3. Control	..		
4. Skatole (0·002% soln.)	16	7·88	4·91
5. „ (0·01% „)	80	7·05	3·98
6. „ (0·02% „)	160	7·66	4·70
7. Ascorbic acid (0·002% soln.)	16	9·64	5·44
8. „ „ (0·01% „)	80	8·29	5·89
9. „ „ (0·04% „)	320	8·35	4·43
10. Sodium β-indolylacetate (0·002% soln.)	16	8·21	5·32
11. „ „ (0·01% „)	80	7·46	4·53
12. „ „ (0·04% „)	320	8·11	4·50
13. Sodium α-naphthylacetate (0·004% soln.)	32	8·19	4·79
14. Sodium α-naphthylacetate (0·001% soln.)	8	8·21	5·35
15. Sodium α-naphthylacetate (0·002% soln.)	16	7·25	5·05
Standard error		0·905	0·512
Significant difference A (to compare any treatment)		2·54	1·44
„ „ B („ control and any treatment)		2·08	1·17

There are no significant differences in this experiment.

Experiment III.—Thirty seeds of white mustard were sown in each of 6 pots on September 3, 1936, and the plants were thinned down to 15 per pot after germination had ended. There were 6 pots per treatment and the applications were made as before, but at weekly intervals from September 3 to November 5, i.e. in 10 equal doses. The same fertilizer mixture was used as in Experiment I. Germination-counts were made daily until germination was complete, and the analysis of Rate Index was carried out. The plants were harvested on November 24. Table 3 shows the treatments and the results.

It is clear that the medium and high applications of skatole and sodium α-naphthylacetate have depressed the speed of germination, that the high rates of skatole, sodium β-indolylacetate and sodium α-naphthylacetate have depressed the yield of tops, and that the high skatole has decreased the amount of root. The only increase recorded is that for amount of root at the lowest rate of sodium α-naphthylacetate.

Experiment IV.—In view of the work of Avery, Burkholder, and Creighton [25, 26], a further experiment was carried out in which white

mustard was grown at four different nitrogen levels. The glazed pots were filled with a mixture of clean silver sand, 6 per cent. well-washed calcium bentonite, and 0·5 per cent. calcium carbonate. Twenty seeds were sown in each pot on July 23, 1937, and a little pea-gravel was sprinkled on the surface of the bentonite mixture to prevent it from caking.

TABLE 3. *Experiment III: Treatments and Results*

Treatments	*Total application, mg. per pot*	*Germination-rate index*	*Mean dry weight, gm. per pot*	
			Tops	*Roots*
1. Control	..	0·624	4·49	1·55
2. Control	..			
3. Control	..			
4. Skatole (0·002% soln.)	20	0·564	5·17	1·53
5. „ (0·01% „)	100	*0·469*	4·44	1·15
6. „ (0·02% „)	200	*0·545*	*2·20*	*0·69*
7. Ascorbic acid (0·002% soln.)	20	0·641	4·67	1·89
8. Ascorbic acid (0·01% soln.)	100	0·662	4·95	1·20
9. „ „ (0·04% „)	400	0·603	4·88	1·51
10. Sodium β-indolylacetate (0·002% soln.)	20	0·619	5·24	1·66
11. Sodium β-indolylacetate (0·01% soln.)	100	0·622	4·13	1·13
12. Sodium β-indolylacetate (0·04% soln.)	400	0·611	*3·62*	1·29
13. Sodium α-naphthylacetate (0·0004% soln.)	4	0·631	5·08	*2·18*
14. Sodium α-naphthylacetate (0·001% soln.)	10	*0·533*	4·48	1·62
15. Sodium α-naphthylacetate (0·002% soln.)	20	*0·461*	*2·92*	1·26
Standard error		0·0282	0·346	0·254
Significant difference A (to compare treatments)		0·079	0·97	0·71
„ „ B („ control and any treatment)		0·065	0·79	0·58

Significant differences from the control are given in italics.

The following total nutrients were applied to all pots in five equal doses:

$Na_2HPO_4.12H_2O$	1·26 gm. per pot
K_2SO_4	0·925 „ „
$CaCl_2.6H_2O$	0·185 „ „
$MnSO_4.7H_2O$	0·005 „ „
$MgSO_4.7H_2O$	0·341 „ „
$FeCl_3.6H_2O$	0·025 „ „
H_3BO_3	0·005 „ „

The 5 doses were applied on July 28, August 6, 12, 19, and 24, 1937. Four levels of nitrogen were obtained by applying sodium nitrate to 4 series (of 30 pots each) at the rates of 0·2275, 0·6825, 1·82, and 4·55 gm. per pot, that is, in the proportion 5, 15, 40, and 100. To each of these series, either sodium β-indolylacetate solution (0·04 per cent.) or sodium

α-naphthylacetate solution (0·01 per cent.) was sprayed or watered on to the pots on 5 occasions, namely, on August 9, 16, 18, 26, and 31. The solutions which were sprayed on contained 0·05 per cent. Agral 2, to ensure better wetting of the foliage. The full list of treatments, for each of which there were 5 pots, is given below:

Treatments in Experiment IV

(1) Sprayed 5 cc. distilled water + 0·05% Agral per dose	Sodium nitrate 0·0455 gm. per pot per dose.
(2) Watered 5 c.c. „ „ per dose	
(3) Sprayed 5 c.c. 0·01% sodium α-naphthylacetate + 0·05% Agral 2 per dose	
(4) Watered 5 c.c. 0·01% sodium α-naphthylacetate per dose	
(5) Sprayed 5 c.c. 0·04% sodium β-indolylacetate + 0·05% Agral 2 per dose	
(6) Watered 5 c.c. 0·04% sodium β-indolylacetate per dose	
(7) Sprayed 5 c.c. distilled water + 0·05% Agral 2 per dose	Sodium nitrate 0·1365 gm. per pot per dose.
(8) Watered 5 c.c. „ „ per dose	
(9) Sprayed 5 c.c. 0·01% sodium α-naphthylacetate + 0·05% Agral 2 per dose	
(10) Watered 5 c.c. 0·01% sodium α-naphthylacetate per dose	
(11) Sprayed 5 c.c. 0·04% sodium β-indolylacetate + 0·05% Agral 2 per dose	
(12) Watered 5 c.c. 0·04% sodium β-indolylacetate per dose	
(13) Sprayed 5 c.c. distilled water + 0·05% Agral 2 per dose	Sodium nitrate 0·364 gm. per pot per dose.
(14) Watered 5 c.c. „ „ per dose	
(15) Sprayed 5 c.c. 0·01% sodium α-naphthylacetate + 0·05% Agral 2 per dose	
(16) Watered 5 c.c. 0·01% sodium α-naphthylacetate per dose	
(17) Sprayed 5 c.c. 0·04% sodium β-indolylacetate + 0·05% Agral 2 per dose	
(18) Watered 5 c.c. 0·04% sodium β-indolylacetate per dose	
(19) Sprayed 5 c.c. distilled water + 0·05% Agral 2 per dose	Sodium nitrate 0·91 gm. per pot per dose.
(20) Watered 5 c.c. „ „ per dose	
(21) Sprayed 5 c.c. 0·01% sodium α-naphthylacetate + 0·05% Agral 2 per dose	
(22) Watered 5 c.c. 0·01 sodium α-naphthylacetate per dose	
(23) Sprayed 5 c.c. 0·04% sodium β-indolylacetate + 0·05% Agral 2 per dose	
(24) Watered 5 c.c. 0·04% sodium β-indolylacetate per dose	

The pots were placed in randomized positions on trucks.

The experiment proceeded satisfactorily, and the plants were harvested on September 3. The results of the statistical examination of the dry weights and of the percentages of dry matter in the plants are given in Table 4. For the dry weights there are no significant first or second order interactions, whilst for percentage dry matter only the interaction of nitrogen and method of application is significant.

The results for dry weight show that the nitrogen effect is very well marked and the highly significant figures indicate that the method of producing the nitrogen levels was efficient; and that sodium α-naphthylacetate has reduced the dry weight of the plants.

The analysis shows that both substances have depressed the percentage of dry matter, and that spraying has given a lower percentage of dry matter than watering, especially at the 15 per cent. and 100 per cent. nitrogen levels.

Experiment V.—In this experiment the 4 levels of nitrogen manuring were produced exactly as in the previous experiment. The pots were sown with white mustard on September 15, 1937, at the rate of 20 seeds

TABLE 4. *Results of Experiment IV*

A. DRY-MATTER YIELDS SHOWING SIGNIFICANT DIFFERENCES (SUMMARY)

Mean Effects of Amount of Nitrogen

	5% *N*	15% *N*	40% *N*	100% *N*	*Standard error*
Dry weight, gm. per pot . .	0·90	1·49	2·54	4·18	0·075

Mean Effect of Growth-substances

	Distilled water	*Sodium α-naphthyl-acetate*	*Sodium β-indolyl-acetate*	*Standard error*
Dry weight, gm. per pot . .	2·36	2·12	2·36	0·065

B. PERCENTAGES OF DRY MATTER SHOWING SIGNIFICANT DIFFERENCES (SUMMARY)

Mean Effect of Growth-substances

	Distilled water	*Sodium α-naphthyl-acetate*	*Sodium β-indolyl-acetate*	*Standard error*
Dry matter, per cent. . .	12·99	11·92	12·41	0·193

Mean Effect of Method of Application of Growth-substance at Different Nitrogen levels

	5% *N*	15% *N*	40% *N*	100% *N*	*Mean*
Sprayed . . .	12·77	12·20	11·79	11·36	12·03
Watered . . .	12·91	13·34	12·02	13·12	12·85
Mean . . .	12·84	12·77	11·90	12·24	12·44

Standard error for individual entries = 0·315.
" " nitrogen means = 0·223.
" " method of application means = 0·158.

per pot, which was reduced to 10 per pot on September 22. There were 24 treatments, as before, but the concentrations of growth-substance were reduced and the applications given more frequently:

Treatments in Experiment V

(1) Sprayed 5 c.c. distilled water + 0·05% Agral 2 per dose . .
(2) Watered 5 c.c. " " per dose . . . .
(3) Sprayed 5 c.c. 0·0025% sodium α-naphthylacetate + 0·05% Agral 2 per dose . . . . . .
(4) Watered 5 c.c. 0·0025% sodium α-naphthylacetate per dose .
(5) Sprayed 5 c.c. 0·01% sodium β-indolylacetate + 0·05% Agral 2 per dose . . . . . .
(6) Watered 5 c.c. 0·01% sodium β-indolylacetate per dose . .

} 5% nitrogen level.

Treatments in Experiment V (cont.)

(7) Sprayed 5 c.c. distilled water + 0·05% Agral 2 per dose	15% nitrogen level.
(8) Watered 5 c.c. „ „ per dose	
(9) Sprayed 5 c.c. 0·0025% sodium α-naphthylacetate + 0·05% Agral 2 per dose	
(10) Watered 5 c.c. 0·0025% sodium α-naphthylacetate per dose	
(11) Sprayed 5 c.c. 0·01% sodium β-indolylacetate + 0·05% Agral 2 per dose	
(12) Watered 5 c.c. 0·01% sodium β-indolylacetate per dose	
(13) Sprayed 5 c.c. distilled water + 0·05% Agral 2 per dose	40% nitrogen level.
(14) Watered 5 c.c. „ „ per dose	
(15) Sprayed 5 c.c. 0·0025% sodium α-naphthylacetate + 0·05% Agral per dose	
(16) Watered 5 c.c. 0·0025% sodium α-naphthylacetate per dose	
(17) Sprayed 5 c.c. 0·01% sodium β-indolylacetate + 0·05% Agral 2 per dose	
(18) Watered 5 c.c. 0·01% sodium β-indolylacetate per dose	
(19) Sprayed 5 c.c. distilled water + 0·05% Agral 2 per dose	100% nitrogen level.
(20) Watered 5 c.c. „ „ per dose	
(21) Sprayed 5 c.c. 0·0025% sodium α-naphthylacetate + 0·05% Agral 2 per dose	
(22) Watered 5 c.c. 0·0025% sodium α-naphthylacetate per dose	
(23) Sprayed 2 c.c. 0·01% sodium β-indolylacetate + 0·05% Agral 2 per dose	
(24) Watered 5 c.c. 0·01% sodium β-indolylacetate per dose	

There were 5 pots per treatment.

The growth-substances were applied every other day from September 27 until October 11, after which the concentrations of the sodium α-naphthylacetate solutions were reduced, since the epinastic response induced by the spraying was very pronounced, and with growth slowing up, recovery from one dose was not complete when the next application was due. Therefore the concentration of the sodium α-naphthylacetate solution was reduced to 0·001 per cent. for both spraying and watering treatments. The strength of sodium β-indolylacetate solution remained unchanged. Treatment was given every other day and continued until October 21. The plants were harvested on October 25.

The results of the statistical examination of the dry-matter yields and percentages are given in Table 5. For the dry weights the only significant interaction is that between type of growth-substance and the method of its application. For percentage dry matter there are no significant interactions.

TABLE 5. *Results of Experiment V*

A. DRY-MATTER YIELDS SHOWING SIGNIFICANT DIFFERENCES (SUMMARY)

Mean Effects of Amount of Nitrogen

	5% *N*	15% *N*	40% *N*	100% *N*	*Standard error*
Dry weight, gm. per pot	0·54	0·73	1·11	1·51	0·038

Mean Effect of Growth-substances using Different Methods of Application

	Distilled water	*Sodium α-naphthyl-acetate*	*Sodium β-indolyl-acetate*	*Mean*
Sprayed . .	1·02	0·84	1·01	0·96
Watered . .	1·04	1·04	0·88	0·99
Mean . . .	1·03	0·94	0·95	0·97

Standard error for individual entries = 0·047.
" " type of growth-substance means = 0·033.
" " method of application means = 0·027.

B. PERCENTAGES OF DRY MATTER SHOWING SIGNIFICANT DIFFERENCES (SUMMARY)

Mean Effects of Amount of Nitrogen

	5% N	*15% N*	*40% N*	*100% N*	*Standard error*
Dry matter, per cent. . .	9·3	9·1	7·8	7·5	0·14

Mean Effect of Growth-substances

	Distilled water	*Sodium α-naphthyl-acetate*	*Sodium β-indolyl-acetate*	*Standard error*
Dry matter, per cent. . .	8·6	8·1	8·6	0·12

Mean Effects of Methods of Application

	Sprayed	*Watered*	*Standard error*
Dry matter, per cent. .	8·2	8·7	0·10

From the dry weights it can be seen that the response to nitrogen is well marked; that sodium α-naphthylacetate has depressed dry-matter production, especially when sprayed on; and that there is a suggestion that watering-on of sodium β-indolylacetate has also depressed the dry-matter yield.

The analysis of the dry-matter percentages shows that increasing nitrogen supply decreases percentage dry matter; sodium α-naphthyl-acetate reduces the percentage of dry matter; and spraying gives a lower percentage of dry matter than watering-on.

Experiment VI.—In view of Cholodny's claims of increased yields following the 'hormonization' of seed, an experiment was made in which white mustard seed was treated by steeping for 24 hours in the solutions of synthetic growth-substance.

The seed was then sown in soil in glazed pots in the greenhouse, on October 22, 1936. Fifty seeds were sown per pot, and there were 4 replicates of each treatment. Germination-counts were made. Plants were thinned to 20 per pot on November 3, and to 10 per pot on

November 9. Throughout all the early stages, the stems of plants in treatments 2, 3, 4, and 5 were considerably longer than in any other treatments. Table 6 gives the experimental treatments and the results from harvesting on December 21, 1936.

TABLE 6. *Experiment VI: Treatments and Results*

Treatments	*Germination-rate index*	*Mean dry weight, tops*
1 and 6. Control (distilled water) . . .	0·763	1·51
2. Sodium β-indolylacetate 50 mg./litre . .	0·790	1·53
3. „ „ 100 „ . .	0·743	1·49
4. „ „ 200 „ . .	*0·668*	*1·12*
5. „ „ 500 „ . .	*0·474*	*0·50*
7. Sodium α-naphthylacetate 5 „ . .	0·710	*1·23*
8. „ „ 10 „ . .	0·698	1·40
9. „ „ 20 „ . .	*0·552*	1·31
10. „ „ 50 „ . .	*0·452*	*1·05*
Standard error	0·0299	0·094
Significant difference A (to compare treatments)	0·087	0·27
„ „ B („ control and any treatment)	0·075	0·24

Significant differences from the control are given in italics.

These results show only significant depressing effects of treatment; there was no significant stimulation.

Discussion

The limitations of the experiments here reported are realized, especially in regard to the restricted range of concentrations and the amounts of the synthetic growth-substances applied. Moreover, allowing ample replication in carefully controlled pot-culture experiments permits the inclusion of only a restricted number of treatments, on account of the magnitude of such experiments and of the labour involved. Nevertheless, certain conclusions can be drawn from the results.

For the compounds, concentrations, and plants described it cannot be said that any stimulation of dry-matter production has been observed. That is to say, in general, selected substances known to be active in some respect, such as causing curvature of the *Avena* coleoptile or stimulation of root-production from stem tissue (e.g. β-indolylacetic acid, α-naphthylacetic acid and skatole), or believed to be present in farmyard manure (e.g. skatole and β-indolylacetic acid), have not increased the total growth of plants under the conditions of our experiments. For each substance used, a negative response has been obtained at the higher concentrations.

In the light of the work by Avery, Burkholder, and Creighton, the experiments at different levels of nitrogen manuring are apposite. At the concentrations of growth-substances used, no positive response to their application has been obtained at the lower nitrogen levels, although there

is a suggestion that sodium α-naphthylacetate has a slight depressing effect at the higher levels.

Avery, Burkholder, and Creighton consider that nitrogen-starved plants are deficient in natural growth-substances. The lack of response to the application of synthetic substances by nitrogen-starved plants in the Jealott's Hill experiments suggests that the dwarfed nature of such plants is not due entirely to a deficiency of natural growth-substance but probably to the nutritional factor itself. It must be remembered, however, that synthetic growth-substances only were used; a totally different result might have been obtained if, for instance, auxin a or auxin b had been used.

Pearse's finding that treatment with growth-substance decreases the percentage of dry matter in the aerial parts of the plant has been confirmed; this applies particularly to spraying with sodium α-naphthylacetate.

Evidence in favour of the claims of Virtanen and others that ascorbic acid stimulates growth has not been forthcoming under the conditions of the experiments herein described. Further extended trials are necessary to clarify this point.

It can also be said that white mustard does not respond to seed treatment in the way described by Cholodny for other species.

Summary

1. Pot-culture experiments are described in which solutions of β-indolylacetic acid, α-naphthylacetic acid, skatole, and ascorbic acid were applied to plants by spraying on to the foliage and by watering on to the sand.

2. At the concentrations used and for the plants named, no significant increases in dry-matter production of the plant have been obtained, but in general decreases have been observed.

3. No positive response to growth-substance treatment has been obtained for plants grown with restricted or ample supply of nitrogen.

4. It has been confirmed that treatment of growing plants with sodium α-naphthylacetate solution, at the concentrations named, diminishes the percentage of dry matter in the plants, compared with plants similarly treated with distilled water.

5. For white mustard, no response has been obtained to treatment of the seed with solutions of growth-substances.

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ON ANIMAL BREEDING[1]

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Objectives.—The purpose of animal breeding is to meet a social demand for some particular commodity or service, e.g. an animal product of a certain kind and quality, an animal so constructed as to be able easily to perform a certain task, or so decorative or quaint as to please.

The objective in animal breeding is the creation and maintenance of types which, in their characterizations, are in complete harmony with their destinies—the purposes for which they are bred. But since every detail of structure and function is the end-result of the interplay, during the individual's development, of heredity and environment, it follows that the breeder is concerned not only with the type and destiny of his animals but also and at all times with their habitat, the conditions under which they live. Type, habitat, and destiny must always be harmoniously related; each reacts with and upon the others, and any considerable modification of any one of them must necessarily be followed by repercussions of equal magnitude among the rest. The purpose of breeding must be reasonable, not merely economically but also and especially biologically; the environment must be optimum, free from all agencies, living and non-living, which cause defect and derangement, and such as encourages the full expression of all advantageous inborn potentialities; the type must be the ideal, that most easily able to profit fully from the optimum environment provided and to yield the commodity or service demanded of it.

Since from time to time and from place to place social demands change and vary, the breeder is set the task of maintaining either a diversity of types, each harmonized to a particular habitat and/or destiny, or else a 'flexible' type which by modifications in husbandry and/or breeding practice can quickly be remodelled.

Since also, and at the present time, animal stocks are maintained in places and under conditions which are such as to make the biologically optimum environment unattainable, the objective in animal breeding commonly comes to be the creation and maintenance of animal types that are in harmony with the best environment which, under the conditions, it is economically possible to create.

At the present time, for reasons which are rooted in economic necessity, animal stocks are being maintained in habitats which are in every respect incurably harsh and entirely unsuitable. In the future, when reason controls our activities, perhaps animal-breeding planning will ensure that animals are bred where they most easily breed and thrive. For the present we must content ourselves with the production of types that give the best performance under given conditions, whilst all the time we strive to improve these conditions.

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If in any given region a uniform environment exists, then as this approaches the optimum there will be a reduction in the number of types that are needed, and the few that remain will show uniformity and will become relatively fixed, whereas in a region which includes a variety of environments a lower degree of uniformity and a greater degree of adaptability will be required.

At all times and in all places the breeder must maintain a high reproductive rate and a low mortality rate, for he is concerned not only with productivity of his stock but also with its reproductivity and its viability.

It is recognized that policies of live-stock improvement necessarily involve synchronized improvement in destiny (marketing), in habitat (husbandry, including nutrition and disease prevention), and in type (the genetical constitution of the stock, breeding systems, standards). Though on occasion specialists may consider these different aspects of one and the same problem separately, the breeder himself in practice can never hope to disentangle them, nor should he wish to do so.

These are the views of a biologist who sees the world through the windows of a laboratory. It may be that the windows distort that which is seen, or protect the onlooker from the fierce winds of financial anxiety. Be this as it may, the fact remains that the breeder is also an experimental biologist, and that his success or failure is determined less by his financial acumen than by his biological expertness. This being so, it may be mutually profitable for biologists to commune.

The fowl.—To give point to these views any one of us could choose a convenient example. I propose to use the fowl, because it has been my collaborator in many an experiment; but the fowl is merely an illustration of all live stock. Society demands a 2-oz. egg (with a white shell and at a certain price). Thus the purpose of poultry-breeding for egg production is the provision of this 2-oz. egg. But in order to meet this demand, and in so doing to secure an adequate reward (according to the standards of our own society), the breeder has to create and maintain a stock of fowls which will mature in less than seven months (i.e. he has to be able to control growth-rate, bodily maturity, and puberty); that will convert say 95 lb. of food into 200 such eggs (he is concerned with the genetical and physiological aspects of efficiency of food-utilization and of fecundity); that will show a fertility rate of at least 85 per cent. (he must know a great deal about the genetical and physiological aspects of fertility); that will show a mortality rate of not more than 10 per cent. (disease-resistance, disease-prevention, viability); and that is of such a quality that about two-thirds of the stock can be profitably retained for a second year of production (he must know all that is known concerning the factors affecting the duration of productive life). These are the objectives in breeding, and be it noted every one of them must be gained and held contemporaneously if the breeder is to build a type that is in harmony with its destiny.

The demand for a 2-oz. egg is reasonable, for it has been shown that the hen can produce 200 or more of these without harm to herself or to her progeny. The objectives are all concerned with biological variables, relating to which a considerable body of scientific knowledge exists.

None of them refers to any particular breed trademark, for the breeder of utility poultry at least knows that there is no such thing as the best breed, though of course he will quite rightly maintain that a certain type (a certain constellation of genetic characters which may or may not include the few superficial characters of a particular breed) is best suited to a particular habitat and for a particular market. In fact 'breed' no longer possesses any considerable importance to the utility breeder; good looks are less important than are the individual's own record of performance, the record of its relatives (pedigree), and the record of its offspring (progeny test). Brothers and sisters, and cousins and aunts are important people in the poultry world.

So many are the qualities that the breeder must maintain in his stocks, so varied are the mechanisms that underlie them, and so incomplete is our knowledge of them, that the general public should not be surprised to find that the breeders have not yet succeeded in doing all that they must do before the industry is placed on a satisfactory basis. It is probably correct to say that the average egg production per bird per year is around 80 eggs, and that these do not average 2 oz. in weight; that about 30 per cent. of all the eggs that are incubated fail to yield viable chicks; that the mortality among pullets is of the order of 20–80 per cent., and nearer 80 than 20; and that stocks must continuously be replaced for the reason that the duration of productive life is so brief. Productivity, reproductivity, and viability are all far removed from what they must be before poultry-breeding can be a profitable and pleasant occupation for breeders as well as for bureaucrats.

It is now recognized that, for a variety of reasons, the affairs of the poultry industry must become the concern of the State. The individual breeder and his organizations are not competent to deal with the complicated problems of disease-prevention, for example, and so these are now to be tackled and solved by a veterinary state service. The fowl is about to make its dramatic entrance into the veterinary curriculum: heretofore it has died miserably in its millions because pets have been rated higher than producers. Furthermore, professional scientists by the dozen are being employed to investigate those problems of husbandry, nutrition, and breeding which, for obvious reasons, cannot possibly be properly examined by the breeders themselves.

Possibilities of genetic improvement.—The geneticist should be well content to be provided with the opportunity for using the fowl as experimental material. It is relatively cheaply maintained, its matings can be controlled, generation succeeds generation fairly rapidly, and it has numerous offspring. Moreover, the characters, the mode of transmission of which is to be studied, are on the whole definite and easily recognized. In live stock generally it is the very indefiniteness of the characters to be studied, and the lack of knowledge concerning the forces affecting their expression, that make genetical experimentation so hopeless. It is very doubtful indeed that serious genetical investigation of meat qualities can be profitably undertaken until the work of Hammond has been greatly advanced and extended. It is useless to attempt to make a genetical study of the price of a pound of beef. Before genetical work can proceed

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the characters to be studied must be accurately described. Moreover, genetical work demands large numbers of animals, and so the geneticist waits upon further developments in the techniques of artificial insemination. Walton and Hammond are, by their work, creating the possibility for useful genetical experimentation with the larger domesticated animals in the near future. When the kind of work that Hammond and his colleagues are doing has advanced we shall be in a position to know how far the animal stocks we now possess are capable of being modelled by husbandry into the desired types. If they can be so modelled, then it will be revealed that they are in this respect genetically satisfactory; if not, then by the application of genetical methods appropriate types must be created. We shall know the limits of modifiability and shall have a much clearer notion of what is genetic in these qualities of economic importance.

It will now be seen that there is an inherent difficulty in the conception of the ideal type having its being in the optimum environment. So many qualities are demanded (for example, high reproductive rate, a rapid growth-rate, tolerance to certain important deficiencies) that it seems very unlikely that one and the same environment can possibly be optimum for the full expression of all of them. Thus the optimum environment for high milk-yield might prove to be far removed from the optimum for a high degree of resistance to disease. However, on general grounds, it is reasonable to hold the view that it is possible, by appropriate methods, to bring together into one and the same hereditary constitution the genes for any combination of characters that have been shown to be genetic. But whether or not the characters corresponding to these genes can be fully expressed by any individual possessing them all, is a question that can only be decided by further experimentation. Physiological incompatibilities may prevent the creation of types exhibiting all the desired qualities expressed to the maximum degree. If this should prove to be so, then either the standard of the ideal must be modified, or other means of equipping the types with all the desired qualities must be devised.

In the meantime the geneticist has his part to play in helping the live-stock industry to concentrate on as small a number of objectives as possible, to rid itself of standards that are based on false methods of evaluating merit, and to develop better criteria for measuring and evaluating live stock and its products. He must also, and at all times, plead that comprehensive schemes of inbreeding should at once be launched for the purposes of genetical analysis and purgation of the stock, and of providing genetically satisfactory material for use in nutritional and other experimentation.

Whilst the methods and practices of the past have accomplished much, giving us the fine breeds of to-day, they seem to be reaching the limits of their usefulness. The past has been dominated by standards that seem now to be more or less unreal, sometimes even misleading, and commonly disregardful of the qualities that really matter—productivity, reproductivity, and viability. At the present time we have not disentangled the effects of the environment from those of heredity and so have no

knowledge of the importance of either. Without such knowledge we cannot know whether modifications in husbandry or alterations in constitution offer the quickest and soundest means of further improvement.

We are unadventurous in breeding, breeders from necessity, for no private individual in our Society can afford to undertake experimentation that is certainly costly and probably in conflict with his own self-interests; nor will the State, because those who guide our destinies are, for political reasons, more inclined to encourage projects which promise information concerning the possibilities of improving nutrition, general husbandry, and of lowering the incidence of disease by the provision of sera and vaccines. While these are proceeding, and while the standards of the ideal are being re-fashioned and trustworthy yardsticks constructed, the job of the geneticist should be the creation of inbred stocks. Inbreeding to the live-stock industry is what track-racing is to the makers of motor-cars. It is the test of constitution, the revealer of hidden faults, the demonstration of ability beyond that ordinarily required. Through inbreeding, strains equipped with vigour and purged of all weakness can be provided for breed-improvement programmes of the future. In order to know what underlies high milk-yield and high egg-yield we must have true-breeding, low-yielding strains. Furthermore, it is not improbable that many of the ideal types of the future will be first crosses between two distinct inbred strains of the same breed.

Though the animal geneticist must wait upon developments in physiology, veterinary science, and husbandry before he can hopefully engage in large-scale experimentation with the bigger animals, even now, were he encouraged, he could make contributions of importance. It is established, for example, that in one and the same stock of laboratory animals families differing constantly and widely in respect of growth-rate, weight-for-age, and in efficiency of food-utilization can be developed. There is no doubt that these characteristics, so important in live-stock economy, are profoundly affected by heredity, and that they can be manipulated by the application of genetical principles. The correct breeding procedure for the production of similar strains of animals of economic importance have been elaborated and await use.

The rations now provided are so constituted that they give protection against shortage of any constituent known to be essential, no matter how extreme the variation among individuals may be with respect to their requirement of that constituent. Since some of these essentials are very expensive, such a practice as this may be a weighty burden. It might prove to be sound policy to create by genetical methods, and this is the only way, strains in which the requirements of some of these more expensive accessory food factors and minerals are reduced to a minimum. In the fowl this objective has already been partly reached; there are strains which are highly resistant to vitamin-B and manganese deficiencies. There is every reason to expect that strains of live stock remarkable for their tolerance of sub-optimal levels of any of these factors and minerals could easily be created.

Veterinary research.—The veterinarian is primarily concerned with the eradication of the environmental causes of defect and derangement.

His task is to wrench the sickle from the grisly hand of unnecessary death and place it in the fist of the butcher. But we have reason to know that the conquest of a plague may herald the coming of a pestilence. A particular disease makes its appearance, grows in importance, wanes and gives place to another, and the discovery of a cure commonly coincides with the expected disappearance of that disease as an important cause of death. We have 'conquered' tuberculosis only to find that rheumatism is the real public enemy No. 1. By the time we have learnt how to conquer rheumatism it, in its turn, will be giving place to something else. So it is to be expected that the veterinarian will 'conquer' fowl paralysis, if sufficient time elapses before the cure is found. Having done so he will pass on, encouraged by his success and its associated rewards, to the conquest of its successor. His task is to gain the power of preventing all the serious diseases which affect the individual during the first half of its natural life span, for the diseases of senescence can be disregarded. It may be that the time has already arrived when more attention should be paid to the power of the individual to resist the attack of disease-provoking organisms. It is established, for example, that by appropriate genetical methods strains of fowls not only highly resistant to specific diseases but also markedly resistant to disease in general can be established. It is not for me to argue that it would be sound policy to attack the problem of disease in this way: I must content myself by saying that it can be done.

Genetical research.—All defective derangements are, however, not caused by agencies external to the individual, many are the direct expression of constitutional peculiarities. Many lethal and semi-lethal genes are known to exist in live stock and to be directly responsible for the death or the profound debility of the individual in whose hereditary constitution they are present. In the fowl, for example, five such genes are the causes of much death during incubation, whilst two others are largely responsible for the peak of mortality which occurs within the first fortnight after hatching. Others are known to be the cause of pre- and early post-natal mortality in the pig, sheep, and cattle. It is not improbable that the elimination of these lethals might prove to be a most effective means of raising the reproductive rate and of lowering the mortality rate in many stocks. But before they can be eliminated they must be discovered, and so another reason for extensive programmes of inbreeding is provided.

If the causes of death among a poultry population are examined it is found that disorders of reproduction, e.g. ruptured oviduct, impacted oviduct, figure very highly. The prevalence of these conditions does not seem to be the direct result of any increase in productivity, and it is difficult to see how they can be prevented by modifications of husbandry. It would seem that selection for egg-number and egg-size is not also selection for an oviduct that can cope with such production. The eye of the breeder has been fixed on the ovary, and the oviduct, which apparently demands special attention, is overlooked. It has been shown by Greenwood that the size and degree of development of the oviduct are dependent upon hormonic control, and until further selection has pro-

duced an oviduct that will efficiently perform the task that is demanded of it, it may be that those now in use should be conditioned by appropriate hormonic therapy. In any case it is the sex-physiologist's aid that is urgently demanded and not that of the pathologist.

The extension of the productive life of the individual is a matter of considerable importance. If, for example, it were possible to develop stocks of fowls which would maintain their first year's performance during a second and a third year, the whole structure of the industry would be altered. Greenwood's work seems to show that it is eminently possible by selection to achieve this objective, and all that is needed is a large-scale exploitation of the procedures already elaborated. In the meantime we must look to Cambridge and to Aberdeen for information concerning the possibility of extending the productive life by means of modifications in husbandry. In the rat it has been shown that the length of life can be extended by reducing the food intake, and in the fowl that neither the fastest nor the slowest growth-rates are compatible with maximum viability.

The attainment of early sexual maturity, the rhythm of the sexual cycle and through this the reproductive rate are qualities that can be manipulated genetically. But it takes time to 'fix' these qualities in a stock. With recent advances in sex and reproductive physiology there has come into being the possibility of controlling them by other and simpler means. The syringe is replacing the seasons, for it is becoming possible by administering the appropriate hormones or their synthetic equivalents to exert a very complete control over the sexual and reproductive activities of our animals.

To me it seems that the time has now come when the live-stock industry must gain the power of controlling the secondary sex-ratio. It cannot much longer remain content to allow the numerical proportions of males and females among the newly-born in dairy herds of cattle and goats and in flocks of poultry to be decided by the operations of blind chance. Such power can be secured and, I think, should be secured. In the domesticated mammals this control, if Walton's work at Cambridge is adequately encouraged, will emerge from researches relating to the separation of the two kinds of spermatozoa. If I may be permitted to be prophetic, and at the same time assume that the policies and programmes of live-stock improvement in the immediate future will be born of a lively intelligence, I predict that the time will come when all the sires that will be used will be congregated in a few centres, and that the beribboned swaggering stallion will be seen no more upon our roads. He will give place to a small glass phial enclosed within a registered letter. Then the progeny test will claim a reliability that at present it cannot hope to possess. In the case of poultry the problem of the control of the secondary sex-ratio will not so easily be solved, for here it is the female that elaborates the two kinds of gametes. In a poultry population, generally, it seems that there are two kinds of eggs: those, being fertilized, destined to yield males, and those which inevitably will develop into females, are elaborated in equal numbers. But careful search may be expected to disclose individuals which habitually yield a preponder-

THE TICKS OF DOMESTIC ANIMALS IN BRITAIN

JOHN MACLEOD

(*Cooper Technical Bureau, London*)

WITH PLATES 1, 2

THE British Isles are not rich in their variety of ticks; only four genera, comprising thirteen species, are represented in the indigenous or established fauna, and, of these four, three are represented between them by four species, all of which are relatively uncommon and of limited distribution. Of the nine indigenous species of the genus *Ixodes*, no more than three are known to attack large mammals, and of these only one, *Ixodes ricinus*, is of national economic importance. The tick problem in Great Britain is therefore considerably simplified in comparison with its colonial presentation, and any review of British ticks from the agricultural angle resolves itself for the most part into an analysis of the ecology, economic significance, and control of *Ixodes ricinus*.

Two argasid ticks, *Argas reflexus* and *A. vespertilionis*, occur in Britain. The latter is confined to bats, and is very rare, while the other, so far as the writer is aware, has not been recorded from any locality other than Canterbury Cathedral.

The genus *Dermacentor* is represented by one species, *D. reticulatus*, which has so far been reported only from Devon, Somerset, and the Aberystwyth area of Wales. The species is common in western France, and it is possible that only in the somewhat comparable climate of south-west Britain does it find in this country conditions favourable for its continued survival. The alternative possibility is that the species has been introduced from France, is gradually establishing itself, and, when it has outgrown the phase of high environmental resistance imposed by its low initial density, may increase in numbers and extend its territory with an accelerating momentum. We possess very little precise knowledge of the environmental relationships of this species upon which to gauge the probability of this alternative. The tick attacks both sheep and cattle, and in Europe transmits piroplasmosis to the horse and dog.

The genus *Haemaphysalis* is also represented by only one species, *H. cinnabarina* var. *punctata*, which has a distribution practically limited to the county of Kent. Outside of this county there are, to the writer's knowledge, only four records of its occurrence, one for Glamorgan, two for Devon, and one for Dorset. In Kent it occurs most commonly in the Romney Marsh district. It is not, however, a marsh tick, its favourite habitat being open plain, as opposed to the more woodland type of territory favoured by *Ixodes ricinus*. The species attacks sheep and cattle, and has been shown experimentally to be capable of transmitting red-water (piroplasmosis) to cattle in England. Its relationship to this disease is discussed later.

The nine species of the genus *Ixodes* known to occur in Britain are:

I. ricinus: on sheep, other mammals, and birds.

I. hexagonus: on hedgehogs, other mammals, and birds.

ance of females. In other forms 'sex-ratio' genes have been identified and are known to disturb the mechanism responsible for the production of the two kinds of eggs. These genes can be incorporated into stocks by appropriate genetic procedures and by their aid a secondary sex-ratio of any desired dimension can be obtained. On the other hand, it may prove to be more desirable to transform the majority of male embryos into females during the earlier stages of incubation by means of injection of 'feminizing' hormones into the egg. Undoubtedly this can be done, but it remains to be shown that such a procedure can with advantage be transferred from the laboratory to the farm.

The breeder.—I will end as I began, by reminding myself and you that the geneticist knows that inborn qualities find full expression only in an optimum environment. The most important feature in the environment of our live stock is the breeder himself. The chief prerequisite in all live-stock improvement is improvement of the men in charge, the practitioners of agriculture, the veterinarians, and especially the improvement of privileged people like myself who are given such plentiful opportunities for self-expression and for public service. The need for new knowledge is urgent, but knowledge remains sterile and wasted until it can be exploited in the true service of mankind. No research is of any considerable value until its benefits can be appreciated by the actual practitioners. Science has contributions to offer, but only to the educated and intelligent. The chief obstacle to the application of genetic principles in live-stock breeding commonly seems to be the inability on the part of the breeder to understand the jargon of the geneticist. Yet the man to whom heterozygosity is a mystery and linkage a myth speaks familiarly of the most intricate details of a tractor.

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The nine species of the genus *Ixodes* known to occur in Britain are:

I. ricinus: on sheep, other mammals, and birds.

I. hexagonus: on hedgehogs, other mammals, and birds.

I. canisuga: on dogs, other mammals, and birds.
I. tenuirostris: on small burrowing mammals.
I. vespertilionis: on bats.
I. brunneus, *I. caledonicus*: on land birds.
I. putus, *I. unicavatus*: on marine birds, the latter chiefly on the cormorant and its congeners.

Only the first three of these are of interest to the agriculturist as potential enemies of farm stock. *I. hexagonus*, the hedgehog tick, appears to be, in the adult stage, essentially a tick of burrowing animals, or at least of animals which penetrate into dense undergrowth for hunting or shelter. It is found occasionally on dogs after a ramble in the country, and appears to be perfectly at home on this host, whose progenitors indeed were in all probability one of its principal host species. The tick has been found on sheep, but it is doubtful if this animal is more than a rare and accidental host. *I. canisuga* is the true dog tick of this country. Although the three members of this genus, *I. hexagonus*, *I. ricinus*, and *I. canisuga*, are frequently found on dogs, this is the only species adapted principally to the dog and able to survive in ordinary dog-kennels. It is chiefly found on sporting dogs, or other working breeds, which are generally confined to kennels for all or a considerable portion of each day.

The immature stages of both these species, and also of *I. ricinus*, are quite frequently found on birds. Thus the larvae, nymphs, and even the adults of *I. canisuga* usually occur on sand-martins, or birds that nest in holes. The larvae and nymphs of *I. hexagonus* are found on the common birds of the country-side and hedgerow, and those of *I. ricinus* on birds whose haunt is the rough moorland or forest.

I. ricinus, the sheep tick, is widely distributed in Britain. Although occurring in greatest numbers in the hill country of Scotland and northern England, it is also fairly common in North Wales and south-west England, and records exist of its occasional occurrence in practically every part of the country where there is rough grazing. The accompanying map shows the areas from which it has been recorded, or at least been recovered to the writer's knowledge. The species attacks sheep, cattle, and deer principally, but will live on practically any warm-blooded host. In this country it is responsible for the transmission of louping-ill and of tick-borne fever in sheep, and of red-water in cattle. It is also suspected of causing by its bite a pyaemic condition in young lambs, and epidemic losses among grouse stock have been ascribed to heavy infestation by the immature stages of this tick.

Biology of 'Ixodes ricinus'

Life-history.—The sheep tick, like all the other Ixodid species mentioned above, is a three-host tick, that is, it attaches itself to a different individual in each of its three stages. The life-history is, briefly, as follows. The eggs are laid at the roots of grass, rushes, or heather. The tiny, almost invisible larva, hatching from the egg, climbs in favourable weather to the tips of the vegetation, from where it attaches itself to any host that happens to brush past. The larva feeds for 3–5 days, then

drops to the ground, where after an interval of time, which varies with the season, it moults to the nymphal stage. The nymph repeats the performance of the larva, and, after feeding for 4–6 days, drops to the

Distribution of *Ixodes ricinus* in the British Isles.

The map shows, from the known records of sheep-ticks in Britain, the relation between tick-distribution and rough hill-grazing. Although no published records exist of the occurrence of the tick in Inverness-shire, north-west of Glenmore, it is probably common in that country. Similarly, the writer has been informed that ticks are fairly common in Yorkshire, but since no locality records were given the area is left blank on the map.

ground, to moult to the adult stage. The male does not feed to any appreciable extent, whereas the female feeds for 7–11 days. Fertilization occurs usually on the host. The engorged female, dropping to the

ground, begins after a week or two the culminating act of her career—the uninterrupted production of a cluster of eggs, which may number 2,000 or more. Her task finished, she lingers on for a week or two, a spent and useless shell, and then dies.

On sheep, the larvae are usually found attached to the lower parts of the legs and round the lips; the nymphs tend to congregate on the face and ears, and under the chin, as well as on the legs, whilst the females are practically all attached in those areas where hair and wool join, i.e. where the wool is short and open. Thus they are mostly found round the neck and ears, to a slightly less extent on the sides of the chest, and on the upper part of the forelegs, and, rarely, round the margins of the bare parts of the thighs (Plate 1, Figs. 1 and 2).

In typical tick-infested areas the average incidence per sheep during the tick season may range from about 15 to over 100 females, the highest average figure obtained by the writer being 106 females—the average for 10 sheep on a Northumberland farm in April 1935. Individual sheep may show counts of over 300 females, in addition to the immature stages. The nymphal and larval incidence has not been examined to the same extent as has that of adult females, but the nymphal incidence for the greater part of the tick-season is about $2\frac{1}{2}$ times the female incidence. Since the eggs are laid in clusters, larvae tend to be picked up in large numbers, if at all, so that one sheep may have no larvae and its neighbour some hundreds.

Marked differences exist in the susceptibility to infestation of different hosts on the same pasture. Among sheep, the long-woolled Blackface tends to become more heavily infested than the Cheviot. The age and condition of the animal also affect its susceptibility; young sheep (hoggs or tegs) are much less heavily infested than adult sheep, and barren ewes less heavily than ewes with lamb.

The life-cycle of the tick in Britain, provided it secures a host at each stage with the minimum of delay, is $1\frac{1}{2}$ years. Each unfed stage can survive for at least a year while awaiting a host, so that the cycle may on occasion be extended to $4\frac{1}{2}$ years. The relation of the different phases of the life-cycle to the seasons is illustrated in Fig. 3.

Relation to climate and vegetation.—Since the tick spends only some 18 days in the parasitic phase out of a total life-span of some 500 to 1,500 days, it follows that for the greater part of its life it will be controlled by factors identical with those affecting the activities of free-living organisms. Temperature and humidity both exercise a controlling effect, the former limiting its periods of activity, the latter its local distribution. The numbers of ticks picked up each day by sheep vary in close agreement with variations in air-temperature. Phenological observations indicate that at air-temperatures below 45° F. the tick is inactive, lying in chinks and crannies in the lower parts of the vegetation layer. Infestation is rare, since it occurs only through hosts lying on, and so warming, such inactive ticks. At higher temperatures the tick climbs to the tips of vegetation, and consequently transference to hosts is facilitated. At temperatures above 60° F., however, it tends to forsake the vegetation tips for the shelter of the vegetation mat. The degree of infestation is

consequently lowered, though a continuous if rather low incidence is maintained through transference of ticks to the noses and lips of browsing hosts, and to hosts lying down at night, or to rest in the daytime. The tick thus finds optimum conditions for ready parasitization of hosts in the moderate temperatures of spring and autumn in this country.

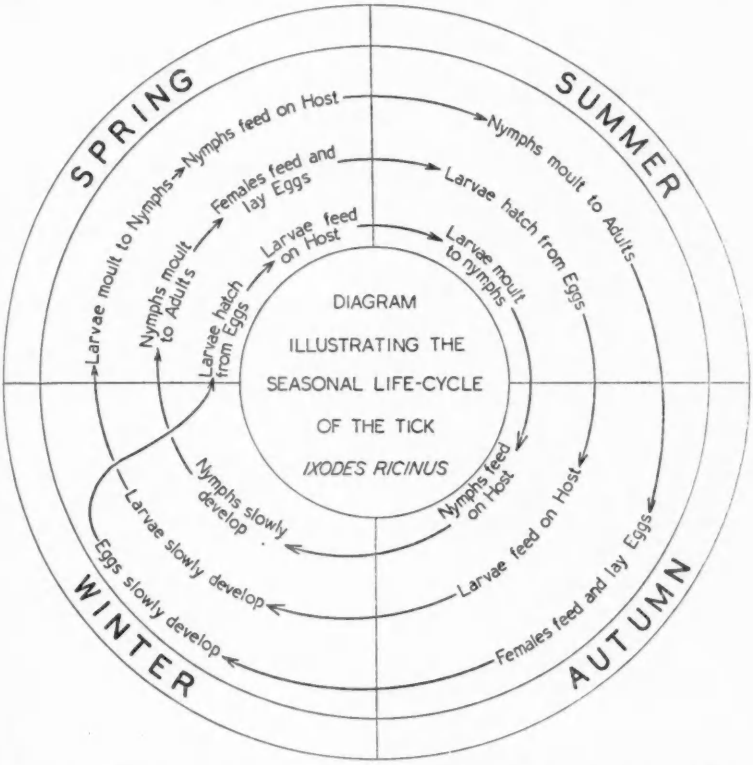

FIG. 3. Illustrating the relation of the different phases in the life of the tick to the succession of the seasons. The complete life-cycle, irrespective of whether it starts from eggs laid in spring or autumn, takes 1½ years.

During the winter low temperatures, infestation of sheep is practically absent, and during the heat of summer it is generally much reduced.

This type of seasonal periodicity has been demonstrated for western and central Scotland, the Border country, and northern England, Wales, and south-western England. There appears to be some doubt, however, whether it occurs in the north-east of Scotland, for on one moor at least in this area the tick incidence has been found to form in the year one single peak, which reaches its maximum in July.

The species, in its free-living phase, is peculiarly sensitive to variations in the humidity of its environment. Under summer conditions

of temperature the unfed tick requires for survival an aqueous vapour tension equivalent to over 80 per cent. saturation, and the gorged tick 85 per cent. saturation or over for development, and 80 per cent. or over for oviposition. Such moisture conditions do not normally occur in the vegetation on well-grazed pastures or meadows; in summer these microclimates tend to dry out through desiccation of the upper inches of soil. Further, where the depth of the vegetation layer is slight, or its structure fairly open, as in lea pastures, meadow pastures, or even good-quality uncultivated grassland, the gradient from the high humidity of the soil pore-spaces to the low summer humidity of the macroclimate is so steep that there is not sufficient vertical range to form a favourable microclimate for survival of the tick. It follows that summer is the critical season for survival of the species in a given area, the possible distribution being limited by the summer moisture requirements to those areas where a saturated or almost saturated microclimate can persist at this season. Such areas are the moors and heaths of the hill country and the forested areas of the lowlands. This same vegetation layer which protects the tick from the excessive heat and aridity of summer will also serve to blanket it, in winter, against the severer excesses of low temperature. Black frosts, which penetrate several inches into the soils of arable and lowland farming areas, are effectively excluded by the heavy layer of moorland vegetation—dead bracken, heather, piled *Molinia*, or mat of *Nardus*—which in winter protects the underlying soil where the tick has sought shelter.

The vegetation type is thus seen to affect tick-distribution only through its effect on the microclimatic humidity. So long as it provides a buffer layer, or mat, over the soil, the specific constitution of the vegetation cover has no influence on the tick density beyond the indirect influence of affecting, by its grazing value, the host density in the area. Thus heavy tick-infestations occur in forest associations, in birch, hazel, or other scrub-wood associations, on moors with a predominant deer-grass, cotton-grass, or bog-myrtle association, on heather (*Calluna*) moors and heaths, on *Juncus* and *Carex* moors, bracken associations, and even grass-moor associations, such as siliceous grassland and other types more characteristic of lowland plains than of hill country. A patchy *Calluna-Molinia* type of grazing, common in northern England and almost always heavily infested with ticks, and a more intimately mixed grass-heather association characteristic of many western Scottish tick-infested moors, are illustrated in Plate 2, Figs. 4 and 5.

The limiting factor to distribution and its bearing on the potentialities of the tick problem.—It is clear from the foregoing summary of the tick's environmental relationships that in Britain the limiting factor to distribution of the species is moisture. Temperatures in our climate are nowhere too low or too high throughout the year to prevent parasitization occurring, and the host-range of the species is so catholic that in Britain, with its high density of mammalian fauna, there can never be a limiting effect imposed on distribution by the host factor. Summer conditions of moisture in the microclimate, on the other hand, vary in different parts of the country from those optimal for survival to extremes

of completely unsuitable aridity. Because of this microclimatic control the tick is confined as a species to well-established areas of distribution, although individual dispersion outside these areas is continuously occurring, through the agency of birds and wild animals, as well as by sheep movement. Ecological succession of vegetation types, in reversion of good pasture to heath, or progressive development of former waste in response to human interference, will result in the occasional development of suitable conditions in areas previously unsuitable or, conversely, in existing infected areas becoming increasingly adverse to survival. Thus around the margins of a tick-infested area there will be an elastic give-and-take of the boundary, signalizing the vicissitudes of the continuous struggle between the species and its environment. A continuous undirectional trend, on the other hand, such as a steady increase of tick-spread over a period of years, or the steady shrinkage of the periphery of a large tick-infested area, is unlikely to occur except in response to a marked change in present practices of animal husbandry, or to a deliberate and maintained system of pasture-conditioning. So long as present farming methods continue, neither a sudden increase of the tick scourge nor, conversely, a marked decline in its intensity need be expected.

Ticks and Disease

Red-water.—Red-water is a popular name for piroplasmosis of cattle—a disease of which haemoglobinuria is an occasional, but by no means a constant, feature. In Britain the causal agent is generally, if not invariably, *Babesia bovis*. The facts that much of the research work was carried out in Britain before this species of piroplasm was recognized as a form distinct from the Texas-fever organism, *B. bigeminum*, and that for some at least of this work the American organism, or a strain of the same species from South Africa, was used by the English workers, have made it doubtful to which organism the experimental work referred. It has, however, been shown by continental workers, and also in England, that *B. bovis* is transmitted in nature by *Ixodes ricinus*. This form of piroplasmosis is widespread in Britain, being endemic in Ireland, the southern counties of England, in Wales, northern England, and in south-western and western Scotland. It has recently been reported also from north-east Scotland.

The presence of the disease usually causes little appreciable economic loss, and in many of the affected animals no symptoms of infection may be observed, the disease running a sub-clinical course which leaves the animal resistant to further attack. The severity of the disease following infection is, however, largely dependent on factors which are at present unknown, and to some extent on exigencies such as sudden changes in weather, e.g. a spring or autumn storm or sudden chill, so that the course of the disease cannot always be predicted, and occasionally an outbreak may cause very heavy losses.

It seems possible that around the Baltic and North Sea coasts there exists a separate type of piroplasmosis, causing sudden death, usually with rupture of the spleen, which is transmitted by *Haemaphysalis*

punctata. It has been suggested that this form also occurs in England. There is not, however, sufficient reliable evidence to indicate whether such outbreaks are in fact due to the piroplasmosis infection, and, if so, whether the causal agent is a distinct species or merely a strain of *Babesia bovis*. That *Haemaphysalis punctata* may in fact transmit piroplasmosis in Britain seems, however, to be reasonably certain. Experiments have shown that it can transmit the disease, and on one red-water farm at least in the south of England (Dorset), the ticks found on the cattle were identified by the writer as belonging to this species.

Louping-ill.—Louping-ill is a febrile affection of hill sheep, due to an ultra-microscopic virus. It occurs chiefly among lambs and hoggs, and recovered animals are immune to further attack. In some cases the virus invades the nervous tissues, resulting in a characteristic syndrome, from certain features of which the two popular names for the disease, louping-ill and trembling, have arisen. Among native acclimatized stock the disease exacts a rather variable annual mortality, which is, however, usually below 10 per cent. of those sheep susceptible, i.e. the lambs and hoggs which are undergoing their first 'tick season'. Where, however, non-acclimatized stock, of any age, is introduced to infected pastures the mortality may be anything up to 100 per cent., and is often over 50 per cent.

Cattle grazing on infested pastures readily contract the disease, often with fatal results. Pigs and horses are known to be susceptible to infection, and cases have been reported of severe meningitis and encephalitis in man, believed to be due to louping-ill.

The disease is transmitted by nymphal or female *I. ricinus* ticks, which have acquired infection in the preceding stage. Infection apparently does not pass through the egg, i.e. larvae resulting from females gorged on infected sheep have, so far, been found to be non-infective. This point cannot yet, however, be regarded as satisfactorily proved.

Hungry infective ticks may retain their infectivity for at least a year, and there is little doubt but that the disease-agent survives the winter in this host.

Louping-ill can be effectively controlled by use of a formolized vaccine prepared from the brain and spleen of infected sheep.

Tick-borne fever.—This is another disease of sheep transmitted by the nymph and female of *I. ricinus*. The causal agent is a rickettsia-like organism which invades the cytoplasm of the polymorphonuclear leucocytes. The disease is rarely fatal under experimental conditions, and its significance in the field would appear to lie less in its direct effect than in the increased susceptibility of the affected sheep to infection by secondary organisms, and in the increased likelihood, as a result of the prolonged and severe pyrexia, of intercurrent infection, such as louping-ill, ending fatally. Since the tick season synchronizes with the lambing season on hill farms, abortion and complications such as metritis are not uncommonly met with as sequelae of tick-borne fever infection.

Recovered sheep possess a tolerably high resistance to reinfection. This appears to be more a kind of premunition than an actual immunity, and will probably be found not to outlast infection in the blood.

Infective nymphs which feed on a refractory animal, such as a hedgehog or rabbit, retain sufficient infectivity to be capable, after their moult to adult females, of transmitting the disease to susceptible animals. In other words, ticks do not cleanse themselves of infection by feeding on non-susceptible hosts.

Unfed ticks remain infective for at least a year.

Pyaemia in lambs.—In many tick-infested areas lambs suffer from a high mortality which cannot be entirely attributed to the recognized sources of mortality under hill-farming conditions, viz. lamb dysentery, pulpy kidney, braxy-like infection (grass-ill), and louping-ill. Investigations in northern England and North Wales showed that in a high proportion of cases pyaemia of one or more of the internal organs was present. This pyaemia sometimes, but not always, involves the joints, when it is often confused with the true joint-ill, of streptococcal origin, due to infection through the umbilicus.

The regular association of this condition with heavy tick-infestation of the lambs has led to the belief that it results either from contamination of tick-bite lesions or, according to some workers, from the transmission and inoculation of the pyogenic organisms by the tick itself. There can be no doubt, from the high frequency of bacterial infection of the sites of tick puncture on young lambs, that tick-bite usually introduces to the wound certain types of bacteria to which lambs seem to be particularly susceptible. Whether the pyaemia which frequently occurs is due in all cases to a specific strain of staphylococcus, and whether such a strain relies for its transmission chiefly on tick-infestation, are problems yet to be solved.

Miscellaneous effects of tick-infestation.—Besides the losses due to specific diseases, various harmful effects may result from heavy infestation of stock by ticks. Infested sheep rub and scratch themselves, to the detriment of the wool clip; burst ticks stain the wool round the neck, and the dried blood, absorbing moisture from showers and drying out again from the warmth of the animal's body, continues to form a favourable nidus for intermittent bacterial activity for weeks afterwards, and is a common cause of neck and shoulder 'strike' by sheep maggots in early summer.

A heavy and prolonged tick-infestation must result in the loss of an appreciable quantity of blood, and many guesses have been made in estimation of its amount. Most of these have involved such wildly improbable assumptions that they have little bearing on actual happenings, and, indeed, any estimate of this nature must be rather idle speculation. It may be of interest, however, to point out that the blood ingested by the ticks represents by no means all of the blood lost. The biting tick injects an anticoagulin into the wound, so that, after the tick detaches itself, an appreciable clot of blood may form over the puncture, as a result of the slow coagulation; and in a larval infestation this amount is much greater than that of the blood ingested. During some work on tick-rearing, large quantities of dried blood were repeatedly found as a fine powder in the infestation-bag, which was attached to the scrotum of the sheep and into which the engorged ticks dropped on detaching. One such quantity, the result of infestation by a single cluster of larvae,

was dried to constant weight and calculated to be equivalent to over 30 c.c. of blood. This result appeared to be excessively high, and a fresh sheep was infested, the gorged larvae being counted and weighed and all the dried blood in the infestation-bag carefully collected. The blood-meal of some 5,400 larvae amounted to approximately 2·68 c.c. of blood and the blood lost from their punctures to over 50 c.c. In another instance the quantity of dried blood accumulated in the infestation-bag during the feeding of successive clusters of larvae over several days was found to be equivalent to approximately 200 c.c. of blood.

Tick-paralysis, a severe and often fatal disease of infested animals, including man, occurs as a result of the attachment of certain species of ticks, and is believed to be due to a toxin present either in the salivary glands or the ovaries and ova of engorging females. The condition is most commonly found in Australia (Queensland and New South Wales), South Africa, and Canada, but has also been recorded from North Africa, the Balkans, and Crete. In this last case the tick believed to be responsible was *Ixodes ricinus*, although *Haemaphysalis punctata* may have been concerned. No natural cases of this disease have so far been recognized in Britain, but the possibility of their occurrence cannot be dismissed.

Game birds, especially young grouse, are often heavily infested by the sheep tick in its immature stages, and it has been suggested by some workers that epidemic mortality occurring among young grouse in certain areas is due directly to tick-infestation. There is no convincing evidence of a causal relationship between tick-infestation and grouse-disease, but, even if this can be demonstrated, it is improbable that the tick will be found directly to cause death under the conditions of infestation commonly found on grouse-moors. It is, however, possible that the tick may act as transmitter of a disease organism, such as *Treponema lagopodis*, which is known to occur in grouse in Britain, and the vector of which has not been demonstrated.

Various accidental effects of tick-infestation are recorded from time to time. These include the possible transmission of diseases normally disseminated otherwise, and also such unusual effects as the disappearance of the attached tick beneath the skin, and severe idiopathic reaction of man to tick-bite.

The economic significance and potentialities of the species may be tabulated under the three heads—specific, non-specific, and accidental effects, as follows:

Direct effects	*Indirect effects*
	Specific
Skin reaction to salivary secretion: recorded in man and horses	Red-water in cattle
Tick paralysis?	Louping-ill in sheep, cattle, man
	Tick-borne fever in sheep, goats
	Spirochaetosis in grouse?
	Pyaemia in lambs?
	Non-specific
Anaemia	Predisposition to blowfly strike
Loss of condition from tick worry	Septicaemia in lambs from tick-bite sores
Loss of wool from rubbing	
Grouse mortality?	Pyaemia in lambs

	Accidental
Burying beneath the skin	Anaplasmosis Anthrax Foot-and-mouth disease in hedgehogs?

Methods of Control

Indirect measures.—The ecology of this species suggests that the host and microclimatic humidity are the only factors that can be influenced so as to effect control. Only the most rigorous reduction of available hosts, as, for instance, the complete removal of sheep-stock, leaving only the wild fauna, could be relied on to reduce drastically the population-level of ticks in a given area. Return of the sheep-stock subsequently would result, after a varying period of years, in the increase of ticks to their former level of density. It is extremely doubtful if the most rigorous and prolonged exclusion of all hosts amenable to control would effect the complete eradication which alone would justify such measures.

It is equally doubtful if eradication could be achieved by manipulation of the microclimatic conditions so as to reduce the humidity below the limits necessary for survival of ticks. The normal habitat of the species is moor, hill, or forest, and in such areas it would be undesirable, even were it possible, to modify the edaphic environment adequately to eradicate the tick. Round the periphery of a tick-infested area, however, there exists, as described above, a form of 'no-man's land' on which the tick may occasionally and somewhat precariously establish itself, because of the deterioration of an edaphic environment normally unsuitable for its survival. In such exceptional cases eradication of the tick may be secured by modifying its physical environment. Such modification is effected by proper pasture management—the correction of sourness or acidity, the elimination of moss and unpalatable grasses, and the maintenance of a close-grazed mat of good herbage. Harrowing, liming, burning, mixed grazing, and similar measures have been recommended in such circumstances.

It would thus appear that indirect measures of control afford little hope of eradication of the tick. Some degree of control of excessively high infestations may nevertheless be secured by such means. Rotational heather-burning results in a shorter as well as a more nutritious herbage; mixed grazing reduces the cover of decaying vegetation under which the tick is protected against summer sun or winter frost, and, further, the hooves of cattle probably help to aerate and break up the layer of humus. Hill-drainage, reduction of wild hosts, and avoidance of overstocking should all serve to reduce, to some slight extent at least, severe infestations of ticks in typical tick country.

Direct measures.—The direct measures which offer most hope of success are: (1) chemical protection of sheep against infestation under conditions where eradication is impracticable; (2) eradication by a system of trapping and killing ticks; or (3) by a combination of trapping and starvation.

Chemical protection. As the expense and dislocation of farm routine involved would nearly always prohibit ambitious attempts at eradication,

the farmer must needs be content with measures that will merely reduce the incidence of ticks on his sheep. Special 'anti-tick' dips are marketed for this purpose, the effect of which is to lower appreciably the degree of tick-infestation on the dipped sheep for periods varying from one to three weeks. The general method of using protective dips is to dip all the flock, including the in-lamb ewes, immediately before lambing begins. A second dipping of all but the ewes already lambed is carried out about three weeks later, the operation being made to synchronize where possible with the round-up, after the third week or so, of those ewes still in lamb. Sometimes a third dipping of all the stock, including the lambs, is given when lambing is over. This is most useful in districts where, or in years when, the tick season continues rather later than usual.

Eradication by trapping involves the complete suspension of ordinary farm husbandry and is applicable where it may be desired to clean up a given area in the shortest possible time. The method consists of running on the ground a heavy stock of eild sheep, which are rounded up and dipped in a suitable acaricide at sufficiently close intervals to prevent any ticks escaping. In practice it has been found best to dip at weekly intervals, thus killing all adult ticks. The sheep are maintained on the ground until either the ticks become inactive or the stock begins to suffer unduly from lack of grazing or constant handling and dipping. The process is repeated for successive tick seasons until eradication, or the required degree of reduction, is achieved.

Combined starvation and trapping has been suggested as a compromise between the requirements of an intensive eradication campaign and the necessity for uninterrupted maintenance of a breeding flock. The writer has had no practical experience of its application, whereas both the foregoing methods have been tested in the field; he believes, however, that it possesses outstanding advantages over the above methods, which should make it useful under certain conditions. The method is indicated where it is necessary to reduce the tick population on a farm, and where it is undesirable that the existing breeding flock should be dispersed, because of its acclimatization to the local conditions.

The principle of the method is to treat one section of the farm at a time by the trapping method. The farm stock is reduced to allow for the reduction in grazing area, and the eild stock is utilized as trap animals for spells of intensive dipping, the treated area being left ungrazed between such spells in summer, but thrown open to the main stock in winter, when tick-infestation is negligible. As this area is intensively or normally grazed for a considerable part of the year, the reduction of stock need not be proportionate to the reduction of the normal grazing area. During the actual period of tick-reduction, exclusion of all sheep from the area after a given spell of trap-dipping should result in numbers of unfed ticks accumulating on the herbage. The subsequent trapping, in the next spell of trap-dipping, should therefore be highly effective, i.e. the same result is obtained, and with a lesser number of dippings, as though serial dipping had been continuous.

When the tick population in one section has been reduced to a sufficiently low level, a part of the main flock is transferred to it after a

precautionary dipping. The second section is then treated, care being taken to prevent sheep on the cleared area from wandering on to infested ground, and other infested sheep from wandering on to the area.

Dips and dipping.—The three principal groups of substances used for sheep-tick control are arsenical salts, coal-tar derivatives, and derris. For trap-dipping or any series of frequent dippings a derris dip should be used, as the other substances cannot be used repeatedly at close intervals. Derris kills attached ticks at concentrations of as low as 1 in 15,000 of ether-extract. At higher concentrations the dip confers a certain degree of protection against re-infestation, the maximum protection, at concentrations within the limit of commercial practicability, being about 10–14 days.

Coal-tar creosote dips (so-called carbolic dips) kill attached ticks if used at bath strengths of not less than 0·35 per cent. cresols or 0·75 per cent. total tar products. They do not, however, afford protection against re-infestation.

Arsenic, as sodium arsenite, is effective against attached ticks at bath concentrations equivalent to 0·16 per cent. As_2O_3; the arsenate and thio-arsenate are also effective against this species of tick. Protection against re-infestation is also conferred by arsenical dips, the duration of protection from a bath concentration equivalent to 0·2 per cent. As_2O_3 being of the same order as the maximum protection conferred by derris. It has been found, however, that whereas the effective duration of derris on the dipped sheep cannot readily be extended by physical means, that of arsenic can be prolonged appreciably by the use of suitable adjuvants. This fact is made use of in protective dips, some of which give a high degree of protection for a period of 2–3 weeks.

Carbolic and derris dips act as contact acaricides, whereas arsenic is generally supposed to be a stomach poison only. It is difficult, however, to explain its action entirely as a stomach effect, and it is possible that it acts to some extent as a contact poison. The effect of carbolic is rapid, immersed ticks usually dying in an hour or two; arsenic takes rather longer, the immersed ticks sometimes taking 24 hours to die, and derris may take 2 days to kill, the effect seldom being apparent in the first few hours. Derris, however, has the effect of almost immediately stupefying unfed ticks to the extent that they are unable to attach, and remain free in the wool in a comatose condition, until they ultimately die. From the protective point of view, therefore, derris is more effective in preventing disease-transmission than is arsenic, which usually does not kill ticks until they have succeeded in attaching and commencing a blood-meal. Carbolic, as stated above, has a negligible protective effect, and ticks which attach within even 2 days of dipping are apparently unaffected.

In dipping sheep for tick control, special care should be taken to immerse the head thoroughly and repeatedly. The great majority of attached ticks are found on the head and neck, and these are the regions generally rather neglected in ordinary dipping practice. With any dip, but with derris even more than with the others, it is important that the individual sheep be kept in the bath for at least a half-minute. Complete

saturation of the fleece may occur in a shorter time, especially with mountain breeds, and in practice the great majority of hill shepherds immerse their sheep for 15 seconds or less. It has been found by experiment, however, that neither the killing value of derris against attached ticks nor the duration and intensity of its protective value is so great in the case of sheep immersed for 15 seconds as with sheep immersed for a half-minute.

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FIG. 1

FIG. 2

FIGS. 1 AND 2. Showing adult ticks in various stages of engorgement attached under the chin and on the shoulder of a Blackface sheep

FURTHER STUDIES ON COMPETITION IN YIELD-TRIALS WITH COTTON

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Introduction.—In a previous paper [1] the author reported the results of an experiment on intervarietal competition in yield-trials with cotton, and he suggested the advisability of arranging field-trials so that competition effects between different varieties would be eliminated.[1]

Since then three other papers have been published on the same question. Hutchinson and Panse [2] carried out five experiments on margin effect in cotton and one in wheat, and they summarized their results as follows: 'Where differences between varieties were great, margin effect was large, and failure to allow adequate plot margins would have resulted in the drawing of erroneous conclusions. Where differences between varieties were small, margin effect was small, and the inclusion in the plots of areas otherwise to be discarded as margins caused a reduction in error which materially improved the efficiency of the experiments.' On the other hand, 'competition between varieties was less than between plants of the same variety. Where margins are dispensed with, therefore, yields will be somewhat overestimated.'

In 1936 Hancock [3] described results with two greatly differing cotton varieties, Delfos and Acala, which were grown in competition over four years. The lay-out of the experiments allowed comparison of all six possible combinations of the two varieties (no competition, competition on one side, and competition on both sides, for both varieties). The differences in yield observed between competition (varying degrees) and no competition were all positive (with one exception) with Delfos and all negative with Acala, during the entire four years. Only three of them, referring to Acala, are statistically significant, although the others may also be found significant if the four-year data are treated together. Since the differences 'no competition versus competition' on one side averaged only 1·4 per cent. for Delfos and 4·01 per cent. for Acala during the four years, the author suggested the use of two-row plots on medium fertile soil. In this way competition to any significant degree would be avoided, and additional land would be available for checking soil heterogeneity by an increased number of replications.

Finally Quinby, Killough, and Stansel [4] gave considerable experimental evidence from which they drew the conclusion that 'cotton varieties differ but little in ability to compete, that they compete the same in a favourable as in an unfavourable season, and that single-row plots can safely be used'. Besides their own data they also considered the figures previously published by the present writer [1], concluding

[1] On p. 235 of reference [1], instead of 'In other words, in case (1) . . . In case (2)', read: 'In other words, in case (2) . . . In case (1)'. On the same page the total sum of squares should be 109·1421, not 108·8060, all the other figures of the table being correct.

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that these data substantiate their findings, which are in complete disagreement with the author's own. As has already been pointed out [2], the statements made by Quinby *et alia* were vitiated by an arithmetical mistake, which when allowed for supports the conclusions of the author.

In the following report an account is given of the work carried out on competition at the Cotton Institute in Greece. The results obtained are based on a great variety of cases and seem to elucidate several points in the problem under investigation.

Method for Detecting Competitive Effects

According to the general principles developed elsewhere [1], competition may be detected by the alterations it causes in the yields of the outside rows of a plot (not protected against competition) as compared with the middle rows (protected). Accordingly, in each case differences $\frac{1}{3}(a+b+c)-b$ were worked out, a, b, and c representing the first, second, and third rows of a plot. If these differences, classified according to variety, are significantly different from zero or from each other, it obviously means that: (*a*) competition effects are undoubtedly significant, and (*b*) their magnitude is such that were all three rows of a plot used for the estimation of yield, the results would be biased substantially owing to competition. It should be noticed that differences $\frac{1}{3}(a+b+c)-b$ are the same as $\frac{1}{3}(a+c-2b)$ used on another occasion.

Experimental Evidence

The arithmetical results of several experiments have been used to test: (1) whether competition always occurs among cotton varieties; (2) whether its effect, if disregarded, causes a significant bias in the results obtained, and (3) the best means of avoiding disturbing competitive effects. Most of these data are now published for the first time, but a few of them have already appeared elsewhere.

In the following paragraphs are reported the arithmetical data of 19 sets of differences $\frac{1}{3}(a+b+c)-b$. The statistical analysis of them was carried out according to Fisher's analysis of variance, and it should be noted that in this instance there is no point in taking block variation separately into account.

Section I.—In 1936 three variety trials were carried out, at Sindos, Levadia, and Verria, according to a randomized-block arrangement. All three trials included the same six cotton varieties, viz. Ingold, Acala, Mexican big boll, Serres (local), 12×8 (a selection from Serres of the Delfos type), and 14×6 (another selection from Serres of the Cook type). In all three trials three-row plots were used, the rows invariably being one metre apart. The length of the rows, the number of replications, and the size of individual plots were as follows:

	Replications	*Length of rows*	*Size of plot*	
		metres	sq. m.	acres
Sindos . .	8	103	309	1/13·1
Levadia . .	5	55	165	1/24·5
Verria . .	6	53	159	1/25·6

The actual yields produced on the three rows of every plot, similar to those given in [1], p. 233, are omitted to save space. Table 1, however, contains the means for plots with or without edge rows eliminated, the differences between them, and the standard error per treatment mean. The yields are expressed in kilograms of seed-cotton per stremma, one stremma being equivalent to 1,000 square metres or 1/4·0468 of an acre.

The data given in Table 1, as well as those not given in this paper, point to the following conclusions:

1. Between the six varieties tested there is an unmistakable difference in yielding capacity.

2. In the Sindos and Levadia experiments, the differences $\frac{1}{3}(a+b+c)-b$ give a significant z value, showing that competition is responsible for an appreciable disturbance in the relative productivity of the above varieties. This disturbance may reach in an extreme case (12×8 and Mexican big boll) 10·5 kg. per stremma (8·6 per cent. of the *b*-rows general mean or 27·1 per cent. of the difference between these varieties) in the Sindos experiment. In the Levadia experiment (12×8 and Acala), it amounts to 15·1 kg. (17·4 or 54·7 per cent. respectively). In the Verria experiment the effect of competition was negligible.

3. The use of all three rows for estimating the yield per stremma resulted in a reduction of the experimental error in only one case (Sindos experiment), whereas in the other two it did not alter the significance of the experiments.

4. The competing value of a variety is greatly affected by the conditions of the experiment.

TABLE 1. *Experiments at Sindos, Levadia, and Verria, 1936*

Various means and their statistical significance

(*Yields in kg. per stremma*)

	Sindos			*Levadia*			*Verria*		
Variety	*Whole plots*	*Middle rows*	*Diff.*	*Whole plots*	*Middle rows*	*Diff.*	*Whole plots*	*Middle rows*	*Diff.*
12×8 .	144·2	137·4	6·8	109·1	117·1	−8·0	104·0	106·2	−2·1
14×6 .	138·1	138·4	−0·4	74·5	73·5	1·0	96·3	94·8	1·5
Serres .	137·3	133·3	4·0	104·5	108·4	−3·9	87·7	86·1	1·6
Ingold .	112·0	110·8	1·2	63·5	61·6	1·9	73·7	72·3	1·5
Acala .	111·8	114·6	−2·8	96·6	89·5	7·1	76·5	76·0	0·5
Mex. b. b. .	94·9	98·6	−3·7	70·3	71·4	−1·0	87·1	87·4	−0·3
S.E. $=\frac{\sigma}{\sqrt{n}}$.	±3·8	±4·6	±2·6	±4·9	±4·7	±2·9	±4·6	±4·8	±2·6

Section II.—Six experiments, to be described here briefly, were conducted in Greece in 1935 and 1936; the data obtained were analysed in precisely the same way as above; their means and standard errors are given in Table 2.

Experiment 1 was carried out in 1935 at Sindos with irrigation: there were 5 local selections and 5 replications. The size of individual plots was 3 rows, 1 m. wide and 100 m. long, or 300 sq. m. (= 1/13·5 acre).

Experiment 2 was also conducted at Sindos in 1935, but without irrigation. The size of plot was 3 rows, 0·80 m. wide and 50 m. long, or 120 sq. m. (= 1/33·7 acre), the number of selections tried and the number of replications adopted being 5.

TABLE 2. *Mean Yields (kg. per stremma) with their Standard Errors of the Six Experiments in Section II*

Experiment 1				*Experiment* 2			
Variety	*Whole plots*	*Middle rows*	*Diff.*	*Variety*	*Whole plots*	*Middle rows*	*Diff.*
X 6	245·5	247·2	−1·7	X 16	86·7	88·7	−2·0
X 9	243·4	228·6	14·8	X 29	82·5	83·0	−0·5
X 15	228·6	228·8	−0·2	X 12	83·8	88·7	−4·9
Serres	222·8	224·8	−2·0	X 26	76·1	76·0	0·1
X 7	210·2	216·8	−6·6	Serres	68·3	73·6	−5·3
S.E. $= \frac{\sigma}{\sqrt{n}}$	±6·4	±8·8	±7·0		±1·5	±2·8	±2·3
Experiment 3				*Experiment* 4			
X 6	87·7	85·9	1·8	26×25	101·6	101·6	0·0
X 9	78·7	80·1	−1·4	29×2	94·5	95·0	−0·5
X 15	77·2	77·8	−0·6	16×2	92·6	92·6	0·0
Serres	75·2	77·9	−2·7	Serres	82·4	78·9	3·5
X 7	66·6	66·4	−0·2	16×3	81·8	82·0	−0·2
S.E. $= \frac{\sigma}{\sqrt{n}}$	±2·4	±3·1	±2·7		±3·1	±4·6	±3·6
Experiment 5				*Experiment* 6			
Missdel	145·9	144·0	1·9	Serres	239·3	239·8	−0·5
C. Foster	140·8	146·2	−5·4	Pelion	115·9	115·5	0·4
Delfos	111·3	109·5	1·7	Fouadi	103·4	101·1	2·3
Serres	81·0	86·2	−5·2	Nahda	84·9	85·1	−0·2
Tsitsiros	60·5	55·8	4·7	Sakelar	77·2	77·0	0·2
S.E. $= \frac{\sigma}{\sqrt{n}}$	±6·9	±8·6	±4·0		±4·9	±5·6	±3·5

Experiment 3 was exactly the same as the previous one. The selections used were similar to those of Experiment 1, sown under dry conditions.

Experiment 4 was carried out in 1936 at Verria with irrigation. There were 5 selections, repeated 5 times. The size of plot was 3 rows, 1 m. apart and 53 m. long, or 159 sq. m. (= 1/25·6 acre).

Experiment 5, also carried out in 1936 at Verria, included 5 Upland varieties and 5 replications; the plots comprised 3 rows, 1 m. wide and 53 m. long, or 159 sq. m. (= 1/25·6 acre).

Experiment 6, carried out in 1935 at Sindos, included 4 Egyptian and 1 local variety. The size of plot was 3 rows, 1 m. apart and 69·5 m. long, or 208·5 sq. m. (= 1/19·4 acre), the number of replications being five.

The figures in Table 2 indicate that the variety means are sometimes significantly different, and sometimes not. In no case, however, was it found that the differences between yields of plots with edge rows

included or discarded were statistically significant, showing that the effect of competition was negligible. On the other hand, the experimental error was always smaller when the yield of all three rows was taken into account, as shown by the standard deviation (per cent. of the mean) given below:

	Experiment					
	1	*2*	*3*	*4*	*5*	*6*
3-row plots . . .	6·5	4·1	6·7	7·8	14·2	8·2
Middle row b . .	8·6	7·6	8·8	11·5	17·8	10·0

Section III.—In 1935 a special experiment was carried out at Sindos, including the varieties Serres (A), Acala (B), and Trice (C). The lay-out of this experiment with the yields obtained is shown in Table 4.

TABLE 3. *Experiment No. 15 at Sindos, 1935. Various Means with their Statistical Significance*

	Yield per stremma determined by			*Differences per stremma of columns*	
Variety	*3-row plots (rows 2+3+ 4−9+10+11 &c.) (1)*	*Middle rows (rows 3, 10, 14 &c.) (2)*	*Rows subject to competition on both sides (6, 7, 17, &c.) (3)*	*1–2 (competition on one side)*	*3–2 (competition on both sides)*
Serres .	222·5	212·2	230·8	10·3	18·6
Acala .	212·1	205·7	194·9	6·4	−10·8
Trice .	229·4	233·9	224·8	−4·5	− 9·1
S.E. $= \frac{\sigma}{\sqrt{n}}$	±9·3	±12·2	±6·9	±7·0	±17·0

In this experiment the yield per stremma can be determined by means of: (*a*) the middle rows, free from competition (like rows 3, 11, 14, 20, 27, 33, &c. of Table 4); (*b*) whole three-row plots subject to competition on one side of each of their edge rows (rows 2+3+4), (9+10+11), (13+14+15, &c.); (*c*) single-row plots subject to competition on both sides (rows 6, 7, 17, 23, &c.). The means and standard errors, given in Table 3, indicate that competition effects either on one or on both sides of a row were inappreciable.

Section IV.—Besides the author's data it was thought advisable to consider some of the experimental results obtained by other workers. Those published by Quinby, Killough, and Stancel [4] are complete enough for this purpose. The results are unique in that the authors concluded that in cotton variety trials the effect of competition is negligible.

The above authors provide two distinct sets of data; those obtained at Chillicothe in the years 1927–9, and those obtained at Chillicothe, College Station, and Angleton in 1933 and 1934.

(*a*) *Chillicothe, 1927–9.* The data given on pp. 270 and 271 of the original paper refer to 19 pairs of cotton rows, protected or unprotected

against competition. They include several varieties, the number of replications for each pair being usually 4. In 5 pairs for every row unprotected there were 2 protected. In these cases the average of the 2 values was taken as the yield for protected rows.

TABLE 4. *Experiment No. 15 at Sindos, 1935. Yields per row, 100 m. long, in kg. of Seed-cotton*

Varieties used: A = Serres (local); B = Acala; C = Trice

(The small letters below denote rows sown to the varieties A, B, or C, just to secure the desired conditions of neighbourhood. They are not taken into account in the statistical analysis.)

Serial no. of rows	*Variety*	*Yield*	*Serial no. of rows*	*Variety*	*Yield*	*Serial no. of rows*	*Variety*	*Yield*
1	c		30	A	24·12	59	a	
2	B	20·03	31	b		60	B	18·72
3	B	23·42	32	A	23·29	61	B	22·87
4	B	22·02	33	A	20·39	62	B	24·75
5	a		34	A	21·81	63	C	23·18
6	B	18·93	35	C	20·36	64	a	
7	C	20·61	36	b		65	C	23·89
8	a		37	C	19·21	66	C	27·10
9	C	20·12	38	C	24·25	67	C	26·11
10	C	19·27	39	C	24·40	68	b	
11	C	20·80	40	A	23·26	69	A	22·73
12	b		41	A	21·60	70	c	
13	A	21·01	42	A	25·01	71	A	20·78
14	A	20·27	43	b		72	A	22·08
15	A	22·04	44	A	20·97	73	A	23·20
16	c		45	c		74	b	
17	A	21·28	46	B	22·68	75	C	24·74
18	b		47	B	20·99	76	a	
19	C	22·41	48	B	22·24	77	C	25·00
20	C	22·42	49	a		78	C	23·92
21	C	21·07	50	B	19·33	79	C	24·15
22	a		51	c		80	B	23·35
23	C	23·53	52	A	24·06	81	B	22·43
24	B	21·82	53	A	21·74	82	B	21·53
25	a		54	A	23·22	83	a	
26	B	18·60	55	b		84	B	18·69
27	B	13·12	56	A	26·32	85	c	
28	B	21·43	57	c				
29	c		58	B	18·66			

Grand total = 1321·33

The yield differences between protected and unprotected rows were taken into account separately for each year. (The method used by the original authors consisted in considering each variety in a separate analysis of variance, which apparently reduced the efficiency of the experiment.) The data for 1927 and 1928 indicate that competition was negligible. For 1929, however, the results are nearly significant. In Table 5 it is shown that differences between protected and unprotected rows are anything but negligible. They vary from −13·7 per cent. of the mean for protected rows (variety Snowflake, in competition

with Delfos) to 11 per cent. (variety Delfos, in competition with Snowflake).

TABLE 5. *Data of the Experiment at Chillicothe in 1929*

Varieties	*Protected*	*Unprotected*	*Difference*
1. Snowflake × Delfos	3·5	4·0	−0·5
2. Delfos × Snowflake	5·1	4·6	0·5
3. L. Express × Acala	5·6	5·2	0·4
4. Acala × Trice	5·5	5·1	0·4
5. Trice × Acala	5·3	5·3	0·0
6. B. Account × Westex	5·1	4·7	0·4
7. Westex × B. Account	5·5	6·1	−0·6
8. Rowden × Sunshine	5·1	5·2	−0·1
9. Sunshine × Rowden	6·0	6·3	−0·3
10. Sunshine × Cl. Superior	6·2	5·6	0·6
11. Cl. Superior × Sunshine	5·3	5·2	0·1
12. Bl. Wagon × Cl. Superior	5·1	5·7	−0·6
13. Bl. Wagon × Mebane	5·3	5·4	−0·1
14. N. Boykin × Mebane	6·0	6·3	−0·3
15. N. Boykin × Kasch	5·9	6·0	−0·1
16. Mebane 4120 × Kasch	5·7	6·1	−0·4
17. Mebane 4120 × Mebane 804	5·8	5·8	0·0
18. Mebane 804 × Mebane 4120	6·1	6·4	−0·3
19. Cleveland × Mebane 804	5·7	5·8	−0·1
S.E. $= \frac{\sigma}{\sqrt{n}}$	±0·46	±0·44	±0·28

Consequently when comparing the varieties Delfos and Snowflake, if instead of the means 5·1 and 3·5 for protected rows the means 4·6 and 4·0 for unprotected rows were taken into account, the actual difference 1·6 in favour of Delfos would become only 0·6, i.e. decreased by 62·5 per cent. (23·3 per cent. of the mean for protected rows of both varieties).

(*b*) *Chillicothe, College Station, and Angleton, 1933–4.* In this experiment three varieties, designated as early, medium, and late maturing, were grown either protected (surrounded by two rows of the same variety) or in competition with the other 2 varieties of each experiment. Differences between protected and unprotected rows are given on pp. 274 and 275 of the original paper, 6 experiments in all being carried out (Chillicothe, College Station, and Angleton in 1933 and 1934) with 6 replications each. The original authors tested 'the significance of the mean of a unique sample', dealing separately with each variety of every experiment. In this work, however, all the varieties of the same experiment are considered together.

In the 1933 experiments, which included the cotton varieties Westex, Mebane, and Greer Wichita, the results did not suggest any significant competitive effect. The 1934 experiments, however, for which varieties Lightning Express, Watson, and Greer Wichita were used, show an unmistakable effect of competition. The interaction varieties × locality is certainly significant. (The respective z value was determined as 0·7105, whereas for $n_1 = 4$, $n_2 = 66$, and $P = 5$ per cent. z amounts to

only 0·4603.) The mean differences between protected and unprotected rows, as well as their standard error $\left(=\frac{\sigma}{\sqrt{n}}\right)$, are given below:

L. Express at Angleton . . .	45·9
Watson at College Station . .	39·2
L. Express at Chillicothe . .	38·8
Watson at Angleton . . .	15·3
Greer Wichita at College Station .	14·4
Greer Wichita at Angleton . .	− 6·3
Greer Wichita at Chillicothe . .	−14·0
L. Express at College Station . .	−43·1
Watson at Chillicothe . . .	−61·7
S.E. $=\frac{\sigma}{\sqrt{n}}$ . . .	±23·9

It is thus obvious that the data obtained by Quinby, Killough, and Stancel point to the conclusion that competition is a varietal character, which is strongly affected by climatic or soil conditions. If not kept properly under control it may bias significantly the result of variety trials.

Discussion

The experiments described above refer to a large number of cotton varieties belonging to several botanical and agricultural groups, and they also cover a wide range of climatic and soil conditions. Any conclusions based on such data may be regarded as representative of the general effect of competition in cotton trials.

(*a*) *Competition is undoubtedly a disturbing factor in yield-trials.* In several cases, like the Sindos and Levadia experiments of Section I, competition effects have undoubtedly been established. The evidence produced indicates that in many cases the inclusion in the calculations of rows not protected against competition causes a substantial bias of the experimental results, which is due to the differential competing ability of cotton varieties.

(*b*) *The nature of competition.* The nature of the competition appears to be very complex. The characteristics that are most correlated with it are almost completely unknown. It may, however, be considered as certain that competition depends on several factors, of which the influence of environment is of outstanding importance. Thus, in 1936, variety Acala grown at Sindos (Section I), was a poor competitor, whereas when grown at Levadia with the same complex of other cotton varieties it was found to be a very strong competitor. The reverse applies to selection 12×8; and a close inspection of the data previously given shows that the competitive value of a variety varies enormously from year to year and from place to place. Therefore it is no use saying that competition between similar varieties is small and between dissimilar varieties is large [4, p. 689]. One never knows which varieties are like or unlike from the competitive point of view. On the other hand, the ability to compete varies so much with varying external conditions that any attempt to classify cotton varieties according to their competitive value seems useless.

This great variability may be attributed to the complex nature of competition. If competition depends on, say, root-development, height of plants, early maturity, size of leaves, transpiration rate, &c., it may so happen that under a definite set of environmental conditions the height of plant is favoured to a great extent. Accordingly, the effect of this character on competition is emphasized, and a classification of the respective cotton varieties according to height will be almost identical with their competing ability for the particular case considered. Under different circumstances root-development or some other character may be the decisive factor, and no one would expect a variety whose root-system is highly developed to possess at the same time all other characteristics favouring competition.

(*c*) *The effect of competition.* Competition may alter the average yield for each variety, giving a false estimate of the comparative yielding value. This happened in the Sindos and Levadia experiments of Section I, and the Chillicothe (1929) and Chillicothe, College Station, and Angleton (1934) experiments of Section IV.

(*d*) *Yield per acre and competitive value vary independently.* From the data provided it is clear that high yielding ability is not necessarily accompanied by strong competing value, or vice versa. The factors, hereditary or environmental, which affect each of these two characters seem to be different.

(*e*) *Variability of plots with one or three rows.* In the Levadia and Verria experiments of Section I the use of all three rows had no effect on the variance of the error. In the great majority of cases, however, the variability of single-row plots (middle rows) was larger than that of three-row plots, presumably owing to the smaller size of the former. Competition also may be responsible for this result. In any case, if competition effects cannot be detected, the use of all three rows will usually increase the efficiency of the experiment owing to a reduction in the variability of the data.

Methods of Procedure

There seems to be no doubt that single-row plots in cotton variety trials are objectionable and should be abandoned. Very little, if any, information is at present available regarding the best number of rows to be used per plot. Two-row plots are, however, nearly as bad as single-row plots, since both rows are subject to competition on one side. Three-row plots, which were used in most of the experiments referred to in this paper, provide a middle row free from, or much less affected by, competition than the two border rows. Therefore three is the smallest number of rows which should be used for each plot and which should generally be adopted in cotton trials. Plots of more than three rows may be more efficient, when one edge-row on each side of the plot is rejected, since a smaller proportion of whole area will then be wasted.

Summary

1. The views of recent investigators concerning the effect of competition are very divergent.

2. Study of the data from a large number of cotton experiments leads to the following conclusions:

(*a*) Competition is undoubtedly a disturbing factor in yield-trials. Its effect is often very significant and may easily be established by appropriate methods.

(*b*) Competition seems to be so complex and to vary so much with external conditions that any attempt to classify cotton varieties according to their competitive value appears useless.

(*c*) A high-yielding variety is not necessarily a strong competitor.

(*d*) Three-row plots usually show a smaller variability than single-row plots.

3. Accordingly, the use of single- or two-row plots in yield-trials with cotton seems objectionable. Three-row plots, from which the two border rows should be discarded, are quite satisfactory, but may be less efficient than four- or five-row plots.

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AUSTRALIAN RURAL INDUSTRIES IN THE ECONOMIC CRISIS, 1929–1935

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I. *Introduction*

1. *The problem of prices and costs.*—The problems of rural industry under the conditions of world economic crisis resolve themselves mainly into the problem of the independent movement of various price-levels. If the prices for both farm and factory goods, for the services which the primary producer buys as well as for the services which he sells, rose or fell at the same time and at the same rate, there would be no need to pay more attention to primary industry than to any other. The prices of different commodities, however, do not move together; those for primary products fall instantly under the fear of oversupply, but other prices fall more gradually, if at all. In particular, the cost of carriage, other than overseas carriage, the cost of capital, and the cost of government, change very little. The rigidity of freights, of interest, taxes, and factory prices, forms the farmer's main problem; and to the extent that he is dependent upon a single main crop he is correspondingly more vulnerable. This generalization, true the world over, is particularly applicable to countries like Australia, whose rural economy is mainly built on the expectation of supplying export markets.

Methods of agricultural adjustment and assistance to producers vary from country to country: the degree of dependence on external markets, the extent of diversification in primary production, the systems of landholding, the intensity of capitalization, and the extent to which collective methods of defence have been worked out by producers, all influence the pattern of relief applied to rural industry. It will, therefore, be necessary to describe the Australian situation in respect to these factors before proceeding to a critical examination of Australian primary production under conditions of world depression.

2. *The diversity of Australian farming types.*—Primary industry in Australia ranges through a great number of variations of a comparatively few industries. For instance, in the chief industry, that of wool production, some stations situated in districts liable to drought are immense in area and rely for their income entirely on wool. At the other extreme, in districts of reliable rainfall, properties varying widely in area obtain their revenue from the sale of sheep or lambs, or even a few cattle, in addition to wool.

In the truly agricultural districts the variation is even greater. Some farmers grow nothing but wheat, although the average farm carries sheep and many produce fat lambs; others grow oats for hay, and

occasionally barley; a few run poultry, and in some cases the farmer's wife earns considerable 'pin money' by milking cows and sending cream to the nearest butter factory. There are a few mixed farms growing crops and hay as well as keeping sheep and running a dairy herd. Even in dairying there is a wide range of activity. Many dairy farmers are concerned solely with the production of cream or whole milk. Others run pigs and occasionally rear stock of various kinds. Some crop and conserve food materials, others buy concentrates. Many are content merely to milk their cows so long as the growth on the pastures will keep the cows in milk, allowing their production to fall away as the annual dry season advances. This is, of course, a primitive type of production, but one which is easily adopted and might even prove to be economical on cheap land liable to great irregularities in rainfall. Orchardists are as varied in their activities as any of the other types. Some are entirely dependent on their orchards, others combine orchards with a small farm, whilst some obtain most of their income from casual work, only attending to the orchard during part of their time and in those seasons when prospects are favourable. Potato-growers and market-gardeners are usually specialists, although peas, marrows, pumpkins, and tomatoes are sometimes produced as side-lines to viticulture and orcharding.

3. *Systems of land tenure.*—The variety of systems of land tenure is responsible for a great diversity in the economic status of the producer. Some freeholds are free from debt, others are heavily encumbered to private mortgagees or financial institutions. Many, again, are in process of purchase from the Crown under a system of periodical payments which cover interest and principal. Leaseholds in the normal sense are less frequent in the better country, and where they occur the leases are for short periods. In the districts of uncertain rainfall, however, leaseholds are usual; and are for long periods at low rates, a significant indicator of the speculative nature of the country. The Crown usually reserves the right to subdivide portions of the property on the renewal of the lease. In addition there are a large number of 'share-farmers' who operate on a system of métayage, providing the plant and doing the work for an agreed percentage of the crop.

Another feature which is necessary to an appreciation of the effects of depression upon rural industry in Australia is the genial nature of the countryside itself—except, of course, in the dry period. The climate in most agricultural districts necessitates little expenditure on clothing; firewood is abundant; stock need not be housed during the short winter; and poultry do well. Under such conditions life can be maintained without difficulty, provided the individual does not demand too much and creditors are not pressing. Further, the majority of farms, as distinct from sheep and cattle stations, employ but a small labour force, and the labour per unit of production is low. Rates and taxes are relatively light when compared with highly developed countries like Britain.

The capitalization of properties, however, is probably relatively high for the greater part of rural Australia. Systems of rural credit sponsored by governments, liberal credit—many believe too liberal—extended by

banks and financial institutions, and hire-purchase methods of acquiring farm and station machinery, have all played their part in increasing the overhead carried by the rural productive system in Australia. Institutions have been as ready to finance the farmer as the farmer himself has been willing to be financed; and, to obtain a true picture of Australian conditions, it is necessary to appreciate the somewhat light-hearted way in which climatic risks have been discounted by hopes.

4. *The principle of state assistance to primary production.*—Largely owing to the important part played by rural production in justifying imports of capital to Australia during the last hundred years, the primary industries came to be regarded as the mainstay of the country. On all sides and at all times the wisdom of assisting primary industry during difficult times has been conceded. Rural producers, under such encouragement, easily developed the habit of turning to the government for assistance in recovery from losses due to drought, or other inescapable calamities. The methods of settlement have, of course, been mainly responsible. Many of the farming areas have been developed by men with little capital, and, as the nation is accustomed to droughts, most of the State Governments, prior to 1930, had become used to the necessity for helping primary producers with small loans repayable in due course. Thus during the 1914 drought the South Australian Government advanced £758,240, of which 95 per cent. was subsequently repaid.[1] In addition, the Commonwealth Government has the power to grant bonuses in order to stimulate industries that are struggling to establish themselves. Thus, before the depression, bonuses had been given on exports of beef and canned fruit, whilst marketing arrangements had been made for sugar, dried fruits, and dairy products, under which the price obtained for the portion of the commodities consumed locally was raised to assist the disposal of the export surplus.

II. *Pre-depression Economic Tendencies in Australian Farming*

The story of Australian farming in the depression begins not in 1930 but in 1915. The circumstances of shipping shortage, of wartime pools, of marketing control, and of guaranteed prices achieved something like a revolution in the 'rugged individualism' that had characterized the Australian farmer. Gratitude for relief from the risks associated with world markets changed, however, to resentment when prices obtained were regularly below world parity. Moreover, in the post-war period, the settlement of returned soldiers on the land and the rise in prices for primary products turned the minds of farmers towards the view that landowning was a grand speculation rather than a way of life. The excitement of the profitable years completely submerged the memories of the sober, steady pre-war years of effort and thrift.

Australian rural industries, however, were not stimulated by inflated prices during the war-period to the same extent as were those of Britain and North America. It is true that the dairy industry went through a boom period owing to the high prices obtained by Australian butter exports on the fat-starved British markets in 1918–21. With this excep-

[1] *Report of Agricultural Settlement Committee* (*South Australia*), 1931, p. 36.

tion, although agricultural prices generally were high from 1917 to 1920, there was no pronounced inflation such as that which occurred in the United States.

During the period 1922–5 almost every primary industry was affected by expansionist policies stimulated by the efforts of the various governments to encourage land-settlement and migration. The market value of nearly every type of land rose unduly in good districts. Well-improved sheep stations changed hands for sums which were the equivalent of £10 to £20 per sheep carried; and dairy farms were sold at prices which represented £100 per cow area. Wimmera wheatland, which could produce an average of 30 bushels per acre in alternate years on a crop-fallow system, sometimes sold at £30 per acre. Similarly, in doubtful country which could not be expected to grow more than an average of 12 bushels per acre on a three-year rotation, wheat farms were sold at £8 per acre. Prices of farm requisites rose in accordance with the general advance in the price-levels of commodities. A situation developed which was extremely vulnerable to a serious fall in primary prices, particularly as much of the trading was done on a hire-purchase basis.

Accumulating difficulties were the prelude to the crisis of 1930. There had been a prolonged drought in inner Queensland in 1926-8; the wheat districts of the eastern part of the continent were seriously affected in 1928; and drought-relief was extended to farmers in many districts. Exporters of apples had received low prices since 1926. The depression hit the various industries at different times, as is shown by the series of graphs in Fig. 1. Wool prices dropped rapidly in 1929; the wheat market collapsed at the end of the year; butter prices declined in 1930–1 and 1931–2, but the levels reached in 1933–5 were even lower.

III. *The Impact of World Crisis on the Australian National Income*

1. *Fall of prices and London funds.*—All this, of course, was merely repeating the history of every major depression in Australia. Ever since the forties and earlier, phases of high prices and bounding prosperity have been terminated by collapse of prices, the drying up of the stream of imported capital, shrinkage in land-values, and prolonged agricultural depression: 1930 was only 1890 in modern type.

It is necessary at this stage to describe briefly the financial nexus between Australia and the outside world. The base of the credit structure is represented by gold reserves in Australia, and sterling funds in London. These London funds are replenished in two ways: (1) by the normal accumulation of credits during the export season, and (2) by the accumulation of loans floated in London. From 1924–5 to 1928–9 exports, including gold, averaged about £145 millions; whilst borrowing abroad averaged about £40 millions annually in Australian currency. This reservoir of London funds was normally depleted by imports; for the six pre-depression years the annual value of visible imports was of the order of £150 millions.

It will be readily seen that a fall in the export price level of 50 per cent., accompanying as it did the cessation of overseas loans, meant a calamitous contraction in the Australian national income from about £600

millions in 1928–9 to about £430 millions in 1930–1. Exports fell from £142 millions Australian currency in 1928–9 to £108 millions in 1931–2. Imports fell even more sharply from £144 to £45 millions. The annual charge for interest on the overseas debt was of the order of £23 millions.

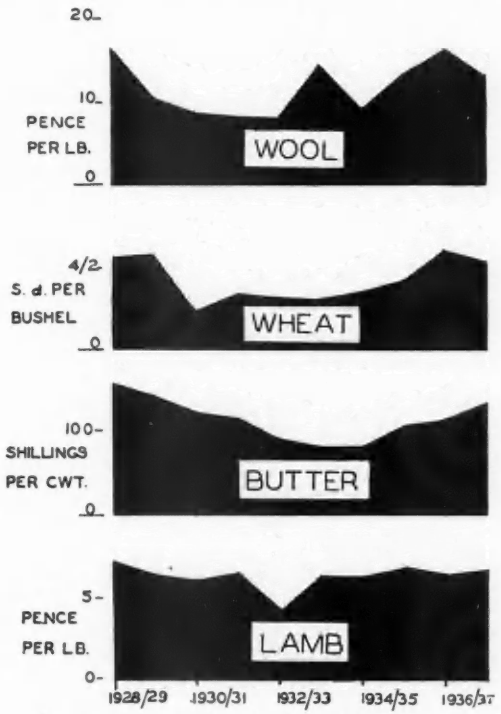

FIG. 1. Export prices of principal Australian rural products, 1928–9 to 1937–8.

2. *The rise in exchange.*—The deficit in the balance of payments was partly met by the export of gold and partly by drawing upon London funds. These reserves were inadequate; and the pressure upon the currency became so serious that, in January 1931, the exchange-rate rose against Australia until £130 Australian currency were needed to pay a debt of £100 in sterling. Since this depreciation of the currency was to play an important part in the restoration of the Australian economy it will be useful to take the discussion a little farther. The monetary dilemma presented by the fall in the national income was whether it was better to aim at stability of internal prices or at external stability of exchange. It was decided that the stabilization of internal prices and, consequently, of the value of all assets including land, was the better plan; and the exchange-rate thereon became one implement for bridging the gap between Australian costs and overseas prices. The chief factor

to be considered in the restoration plan was the maintenance of primary production and, consequently, of exports. The 'exchange bounty' meant that the farmer in Australia received £130 in Australia for every £100 realized in London for exports; and there is little doubt that the moving of the exchange did a great deal in enabling Australia to maintain production and export. It is true that the producer was exporting more goods for less cash than at any time for a generation; but his returns, taken in conjunction with debt-adjustment and other forms of relief, were sufficient to tide him over the crisis and to prevent a total collapse of the whole rural economy.

3. *The drive for increased export production.*—Stimulated by the national emergency, a drive for increased production became inevitable. Intense 'Grow More Wheat' campaigns developed in the eastern states; but the increased output, in fact, only served to swell the surplus which was glutting world markets. At the same time, pasture-improvement campaigns were launched in various states where grassland investigators had been for some time engaged upon the general problem of betterment. At this juncture great benefit began to accrue from the expert knowledge and advice of Mr. William Davies of Aberystwyth, who visited many districts at the invitation of the Commonwealth Council for Scientific and Industrial Research in 1931–2.

The first stage in the improvement of pastures in better rainfall areas was almost invariably the application of superphosphates as a top-dressing. In 1932–3 the Commonwealth Government assisted the movement by allocating a sum of £250,000 to be distributed as a bonus on superphosphates used otherwise than for wheat production. This represented about 15*s.* per ton on all superphosphate used. As the price of superphosphates per unit of P_2O_5 was already low in Australia, this stimulated pasture-improvement schemes. The bonus on superphosphate was continued in later years; and it is still in force with some limitations in the amount of fertilizer supplied to each individual. Up to June 1937 £1,356,000 was allocated in this way. Butter factories and other organizations arranged credits for the purchase of fertilizer, so that the farmer was not handicapped by the difficulty of obtaining the necessary cash. To the extent that this movement resulted in an increase in the volume of production, it may be regarded as aggravating the problem of marketing; on the other hand, it improved the quality of pastures and the standard of management in many districts, and set in motion a development which is effecting steady improvement in land-utilization. The dairy farmer, for example, saw in it a means of making land of £100 capital value carry two cows instead of one at an extra cost of about 8*s.* per annum.

The actual increase in dairy production during the depression was most marked, as the following table shows:

Production of Butter and Cheese. Australia. 1928–9 to 1935–6 (million lb.)

	1928–9	*1929–30*	*1930–1*	*1931–2*	*1932–3*	*1933–4*	*1934–5*	*1935–6*
Butter . .	289·8	299·0	350·4	390·6	419·7	450·9	469·1	433·7
Cheese . .	30·2	30·2	33·1	31·4	36·9	38·5	40·0	38·6

This result was only partly due to pasture-improvement. The climatic conditions were favourable in the dairy districts in 1930–5; and, in addition, the prospect of monthly cash payments for cream induced many farmers who had previously avoided the drudgery of dairying to start keeping a few cows.

Although the primary reaction in many industries was the natural but irrational one of increasing production, it is doubtful if farmers would have approached the problem with the confidence which they showed had not the fall in prices been cushioned by the alteration in the sterling value of the Australian pound, which was mentioned earlier. The immediate effect was to keep the price in Australian currency which the butter factories and the wheat merchants could offer to their farmer clients about 20 per cent. higher than it would have been.[1] There was some appreciation in wool values, but, owing to the different system of selling, the effect of the exchange-alteration was somewhat retarded. The depreciation of currency thus raised the prices on the local market, which to some extent narrowed the margin by which the cost of production exceeded selling-price on most farms at that time. It might have been expected that a consequent adjustment in the costs of commodities purchased by farmers would have taken place. This, however, actually did not occur, because wholesalers and retailers, having considerable stocks on hand, and being faced by contraction of demand, were not prepared to raise their prices to the consumer, except possibly in the case of imported articles which happened to be in short supply.

It seems certain that this tempering of the economic blow which the farming industries were suffering was of some importance. Another, and probably more significant, factor was the general spirit of the time. The Australian people as a whole were forced to face the problem of a deficit in the balance of payments undisguised by the influx of overseas capital. All sections of the community realized that, as a result of the decline in national income, widespread adjustments were necessary. All sections of the people had to contribute to the inevitable sacrifice. Interest rates on Government loans, mortgage-rates, civil service salaries and pensions, the award rates for wages, as well as profits over a wide field of industry, were all compulsorily reduced. This removed the suspicion that the city was profiteering at the expense of the country. Further, as unemployment figures rose, farmers and others working on the land realized that they were better off living a fairly independent life in the country, even if conditions were hard, than they would be tramping the streets of the city looking for work. These psychological influences doubtless helped to keep rural producers at work, although in some of the marginal wheat areas the spirit of dissatisfaction was becoming acute by 1933.

IV. *Types of Cost Structure in relation to the Economic Crisis*

1. *The composition of the cost structure.*—Fig. 2 illustrates in a very rough way the relative distribution of the main items of the cost of pro-

[1] The benefit of the exchange was not quite the same as the full exchange-alteration, because the transport charges from Australia to overseas markets were mostly in sterling.

duction on four types of farm. Some definition of the charges which are included in these subdivisions is necessary. The 'rent or interest' item is the interest charged on the whole of the capital invested in the farm and in the stock and machinery. It includes, therefore, interest on the farmer's own money as well as on sums which had been borrowed in one way or another. The labour cost includes a sum for the work done by the farmer himself and his family, as well as for both permanent and hired hands. The maintenance figure includes maintenance of machinery as well as rates and taxes, the maintenance of buildings, and an average figure for power used and the sundry items which are inescapable on a farm. The transport and marketing group of costs includes

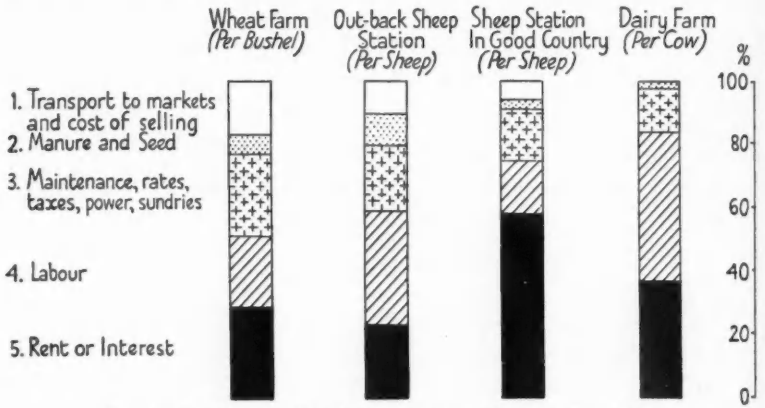

FIG. 2. Percentage distribution of costs of production, 1931.

only those charges which are involved in bagging or baling the produce and in transporting it to the ship's side in the case of wheat, or to the metropolitan selling centre in the case of wool.

2. *Means by which cost items were reduced or avoided.*—Fixed capital charges were lowered by the compulsory reduction in mortgage-rates under financial emergency acts passed by all State parliaments. In addition, every State passed moratorium legislation which prevented the mortgagor from taking proceedings against a defaulting mortgagee if the latter could prove to a special court that he was doing his best and had a chance of recovery. In New South Wales mortgagees were liberated from the liability of the 'personal covenant' clause. The moratorium legislation was continued in each State from year to year; and, finally, in 1935, the Commonwealth Government, in which the administration of the Bankruptcy Act is vested, encouraged the States to set up debt-adjustment boards for the purpose of clearing up the debt position except in the case of debts due to the Crown. To this end the Commonwealth Government agreed to make £12 millions available as a contribution towards the settlement of claims which could be settled by negotiation between debtors and creditors. Money owing to the Crown usually took the form of payment for land or repayment of advances

made to enable settlers to establish themselves on their farms. This was dealt with by the re-appraisement of debts on a new basis; and, as a result, the settlers obtained very considerable relief from the burden of over-capitalization under the lower-price income-structure of depression. Very large sums of money have been written off or, to be more accurate, transferred to the general public indebtedness on this account.

Speaking generally, financial institutions which had advanced money to farmers for carrying on their operations were very unwilling to take over properties from the farmers. In many cases they found it necessary to advance further sums to enable men to carry on till prices rose, in the hope that by so doing they would protect the financial interest which they had previously acquired in the holding. It is scarcely necessary to say that these further advances were only given sparingly. In fact, every farmer coming under a scheme of this kind was rigorously rationed in regard to the credit upon which he could draw.

The cost of labour on probably the majority of Australian farms largely represents the reward of the farmer himself. It was, therefore, not difficult to effect some reduction in this particular item of the cost. Hired labour on wheat and dairy farms is not, as a rule, protected by industrial awards. Payments which are made to farm labourers vary widely from case to case; and it is impossible to state an average figure with confidence. It is certain that expenditure on this class of labour was extensively reduced, in some instances by the replacement of hired labour by family labour, in others by reductions of wage from about £2 or £2. 10*s*. per week plus keep to £1 or 15*s*. plus keep. Cases in which men continued to work for their keep alone certainly occurred. On the other hand, labour on sheep stations is protected by awards; for example, rates for station hands in N.S.W., Victoria, and South Australia were lowered from 85*s*. per week in 1930 to 54*s*. 6*d*. in 1932, and the award for shearers was reduced from 41*s*. per 100 in September 1927 to 27*s*. 3*d*. per 100 in 1932.

The maintenance item was reduced by accepting a lower standard of up-keep than had been customary. Old machinery was made to last longer than usual; tractors were replaced by horses; fences and buildings were patched where, under normal circumstances, they would have been replaced. This state of affairs could go on for a few years without a wholesale loss of efficiency; but the recovery in prices brought with it the necessity for spending large sums in capital rehabilitation. The manure item, also, was occasionally reduced by using less superphosphate; but, on the whole, this was a very bad economy.

It was not possible to make much reduction in the transport section; but, in the wheat industry in New South Wales, the depression had the effect of forcing farmers to relinquish the practice of buying bags, and to use the silos which the Government had erected at many sidings during previous years.

3. *Effect on the individual industries.*—On the wheat farms, as soon as the operators had learnt that the way out of the depression was not by growing an increased acreage, there was a definite swing to the introduction of more sheep and a diminution of acreage under crop. This

resulted in some improvement in the general agricultural practice in many instances; and certainly made farmers pay more attention to forms of production previously regarded as of minor importance. Unfortunately, the men who were most seriously affected were those who were engaged in the development of new farms when the depression arrived. They had had little time to earn much; and had often incurred considerable capital outlay. Many of the new farms were in areas where the climate entailed risks, and in some cases the soil was not suitable. In Victoria the less reliable sections of the wheat area were considered in detail; and, in a number of districts, groups of holdings were amalgamated so that the farming regimen might be switched over from one of wheat with a few sheep to one of a fairly large flock of sheep with a small area under wheat. To do this the Closer Settlement Board in Victoria was empowered to write off the debts of the less satisfactory settlers, and to give them a cash payment, up to £100, on the relinquishment of their properties. The case of the British migrants who were settled in these areas came up for review; and several hundred families were repatriated and compensated. The net result of this readjustment of farm areas has been most beneficial; and some of the more northerly districts have a much better chance of success than they had previously. Except in these districts the average farmer carried on, because, even though he might be heavily encumbered financially, yet those who had lent him the money were either unable or unwilling to evict him.

Sheep stations of the better class were in many cases not heavily encumbered; and a considerable reduction in costs could be effected through the simple process of the owners foregoing any return on the capital invested. There was a reduction in labour costs, and a temporary relinquishment of maintenance charges together with a reduction in 1932–3 of the previous year's Commonwealth land-tax to the extent of one third, followed next year by a further reduction to one half. This measure enabled most of the owners to continue in production. At the same time they were forced to think in terms of improving the returns from their land; and an active policy of pasture-improvement was often adopted with the idea of increasing the efficiency of the holding.

The out-back sheep stations were in a somewhat worse plight. On them it was impracticable to increase the returns by carrying more sheep without at the same time running grave risks through the danger of overstocking. It was fortunate that the seasonal conditions during the depression did not present the serious difficulties which were characteristic of the periods both before and after this particular period. A certain number of blocks were relinquished; but there was no wholesale abandonment such as had been characteristic of these districts when faced with disaster in the nineteenth century.

The dairy industry was extremely fortunate in that the years 1930–4 were generally favourable. There was a widespread and long overdue reduction in rents and in land-values. The labour cost on the majority of farms represents the return to the farmer and his family for their labour—an item which can be reduced without great difficulty. Further, the favourable seasons led to a great development of the practice of

conserving reserves on the farm in preference to purchasing them from outside.

In addition to these general adjustments the Commonwealth Government gave bounties to wheat farmers during the years 1929–35. The total sum distributed on this account was £14,438,791. The fruit-growers were assisted to the extent of £260,000. The Ottawa Agreements were of little or no significance to the producers of wheat or wool, but they undoubtedly assisted in enabling the dairy industry to face the considerably expanded volume of production which came on to the market in the years 1931–5. The price of lamb and mutton was also assisted through the meat agreement and indirectly this helped both the wheat and wool farmers.

4. *Conclusions.*—Reviewing the adjustments forced by depression, it is now possible to point to some of the 'uses of adversity'. In general there can be little doubt that hard times have produced greater individual efficiency on the part of the farmer, as well as a more discriminating outlook upon rural problems on the part of governments. There has developed a greater realization of the relation between primary, secondary, and tertiary industries, as well as a wider recognition of the interdependence of farm and factory. This may be regarded as the economic aspect of a new national outlook. In addition, financial interests have shown a growing sense of social responsibility, and a willingness, under pressures of various kinds, to co-operate in national restoration. Finally, and perhaps not less significantly, primary producers have developed an intensified political consciousness in common with their brothers in adversity in most other countries. Whether this represents progress or not, the urge for sectional security is strong and undeniable.

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THE RABBIT MENACE

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RABBITS have become a very serious pest in Australia, New Zealand, and Great Britain, and in parts of the United States. In most other countries where they are found they appear to have been kept down fairly well, either by their natural enemies or by the hand of man. The object of this article is to outline the scope and nature of the problem constituted by the rabbit, and to indicate some of the methods by which this animal has been exploited commercially on one hand, and controlled as a pest on the other.

New Zealand.—In New Zealand the law with regard to rabbit-destruction is very severe; a landowner who fails to keep down his rabbits when a notice is served on him by a Rabbit Inspector is liable to a fine of £100, and to a continuing fine running up to £100 per month for continued failure. (Incidentally, there are penalties for threatening, assaulting, or using abusive language to a Rabbit Inspector!) Rabbit districts are constituted and are administered by Rabbit Boards, each of which consists of a Rabbit Inspector and 5 members elected by the ratepayers. These strong provisions, enacted in 1928, have been only partially effective. In 1936 no fewer than 17 million skins were exported from New Zealand, in 1937 there were 12 million, and in the first 11 months of 1938 there were 10 million. It is difficult to say how far these figures may have been affected by the price of skins, and how far they may represent a cyclical fluctuation in the rabbit population, such as has been shown to occur elsewhere. The Department of Agriculture claims in its annual report for 1937–8 that 'on the whole the position can be regarded as satisfactory, and that the successful functioning of existing Boards is leading to the constitution of further Boards'. The means principally used for killing rabbits in New Zealand is the poisoned bait.

Australia.—Twenty-four wild rabbits were introduced into Australia at Barwon Park, Geelong, in 1859. To-day the descendants of these animals have flooded the continent and have actually reduced some previously fertile regions to the condition of a sandy desert. Strenuous efforts have been made by the erection of rabbit-proof fences and by the use of every imaginable means of destroying rabbits to get the menace under control, but the success achieved has been very restricted.

Side by side with these efforts for destruction are the activities of the rabbit-trapping industry, which has reached enormous dimensions. A paradoxical fact observable both in Australia and in Great Britain is that the more the rabbits are trapped, the more they seem to increase. David G. Stead, who made an extensive investigation of the rabbit menace on behalf of the Government of New South Wales, compared the rabbit-trapper to a man working a crop of lucerne: 'he cuts down the crop to a certain extent, knowing that the healthy plants are there and that he may shortly come back and take yet another crop'.

The Australian rabbit-trapper may work either for skins or for carcasses or for both. The carcasses he carries to the freezing works, and when the skins are fetching low prices the frozen rabbits may be exported with their fur on. When the price of skins is high, on the other hand, the trapper may find it worth his while to throw away the carcasses and use all his transport for carrying the skins. It is interesting to note that the export of frozen rabbits from the Commonwealth dropped from 13 million pairs in 1917–18 to 5 million pairs in the following year, while the export of skins rose from 72,000 cwt. to 118,000 cwt. This result was doubtless due to a rise in the price of furs on the outbreak of peace. The Australian trapper lays out rather fewer than 100 traps at a time, whereas an English trapper uses about 250. The Australian collects his rabbits with the help of a highly trained dog which has been taught not to tread on the traps. When he is out for carcasses he takes each rabbit out of the trap and puts it into a sack; when the sack is full enough of rabbits, some of which are suffocated and most of which have broken legs, he proceeds to kill his quarry, and hangs them up to bleed in order that he may conveniently collect them later. On the other hand, when the trapper is after the skins only he will very often use poisoned bait, such as strychnine on thistle root, which has the disadvantage of destroying a great deal of wild life and stock. Neither of these methods has had the effect of permanently keeping down the rabbit population, and I shall come presently to the methods best suited for that purpose.

Great Britain.—In Britain also rabbit-trapping has become an industry in recent years, and one which has proved disastrous to genuine agriculture. Rabbits do not appear to have been unduly troublesome in Britain until the middle of the nineteenth century; indeed, from a little book entitled *The Universal Directory of Taking Alive and Catching all Kinds of Vermin*, published in 1768, we find that the main difficulty at that date was to keep one's rabbits from being eaten by foxes, rather than to keep one's crops from being eaten by rabbits. In the middle of the nineteenth century, however, rabbits were beginning to become troublesome; this was possibly due to intensified game-preservation, which involves the killing off of their natural enemies as well as their preservation against poachers. In this connexion it is interesting to note a more recent experience. Captain W. H. Buckley, Master of the Carmarthen Fox Hounds, has recounted that 'there are farms in West Wales which, when trapped for the first time by commercial trappers in 1916–18, produced 200 rabbits, a dozen foxes, 30 to 40 weasels and stoats, and odd cats, dogs, &c. Since then these have produced, and are still producing, 2,000 to 3,000 rabbits every year.' On the other hand, the breaking up of large landed estates has made concerted action against rabbits more difficult, and is probably one great cause of the present plague in Great Britain.

Until 1880 an English farmer had no power to kill rabbits unless he happened to hold the shooting rights, but in that year the Ground Game Act gave every tenant farmer the inalienable right to kill rabbits on his farm. This right has led farmers to look upon the rabbits with a possessive eye as a piece of their property, and the animals have continued to

increase rather faster since the Act was passed than they apparently did before.

It was not until the War, however, that the rabbit menace in Britain assumed really dangerous proportions. West Wales provides the instance in which the history of this development can be most clearly and certainly traced in detail, though the south-western counties, East Anglia, Yorkshire, and other parts are also smitten with the plague. In West Wales before the War there was a moderate rabbit population, and if ever the rabbits became too numerous the farmers would send for the local mole-and-rat-catcher, who would bring his ferrets and quickly dispose of the trouble. During the War, however, the price of rabbits rose to 2*s.* 6*d.* each, and a man who had already been trapping rabbits on the cliffs at Pendine Sands began to buy the right to trap on the farms in his neighbourhood. The farmers readily accepted cash down in exchange for these rights, and gradually the system extended over the greater part of two or three counties. In this way a rabbit-trapping industry of enormous dimensions sprang up, and rabbits have increased to such an extent that grass-farming has in many places become unprofitable even on good land. This has happened at a time when modern methods of grass-improvement are holding out a promise of better times for those who can get rid of their rabbits, and the Carmarthenshire farmers are now demanding the abolition of the rabbit-trapping industry.

The seriousness of the problem can be judged from the fact that between 1922 and 1930 no fewer than eight Bills were introduced into the British Parliament with the object of giving power to local authorities to compel the owners or occupiers of land to destroy their rabbits when these were becoming a nuisance to neighbours. Every one of these Bills failed to pass into law because of opposition from sectional interests. At the time of writing, another Bill, called at first the 'Crops (Prevention of Damage) Bill', but now decamouflaged as the 'Prevention of Damage by Rabbits Bill', has passed its third reading in the House of Lords. It was introduced by Lord Sempill on behalf of UFAW (The Universities' Federation for Animal Welfare), and every hope is felt that it may have more success than its predecessors, for it deftly avoids the shoals on which former craft of a like nature have been wrecked, and was preceded by a campaign for educating public opinion.

It is necessary to be quite clear on the fact that rabbits are a pest and not an asset. Experiment has shown that between four and five rabbits eat as much as one sheep, but the mischief does not end there. Rabbits are selective feeders, and the composition of pasture rapidly deteriorates when large numbers of rabbits are allowed to feed upon it. A quantitative experiment made at Dauntsey's School in 1936 showed an enormous increase of moss, a considerable increase of inedible weeds and useless grasses, and a rapid decrease of clover and useful grasses when rabbits were put into a pasture plot whose composition was sampled from time to time in the course of some fifteen months. Replies received in response to a questionnaire issued by UFAW to West-country farmers some time ago indicated that rabbits are estimated to do damage worth approximately five times what the farmer gets for the sale of the

animals. Even on poor land the rabbit is a pest, for he naturally tries to migrate to richer pastures, and he also prevents his habitat from being improved by modern methods.

Having decided that the rabbit is a pest, and not an asset—at all events when he occurs to the number of anything more than one to an acre or two—and that his market value is the principal reason for his survival, we must now see what are the best methods of keeping him under control.

Methods of Control

Fencing.—In Australia, fencing is considered to be the first requisite. Unfortunately fencing is very costly, and a single defect such as a hole, a loose-fitting gate, a jumping-off point near the fence, or some means by which the rabbit can climb over, is sufficient to render useless a length of fencing which may have cost scores of pounds; and it must be remembered that a young rabbit can squeeze through a 1½-inch hole. Nevertheless on large farms, such as are found in Australia, good fencing appears to be the first requisite. In Britain, on the other hand, fencing on a lavish scale is hardly practicable in view of the large numbers of roads and the heavy traffic on them. In the next place, it is important in Australia to destroy cover and burrows and fallen trees after the rabbits have been killed, and to keep the surviving animals on the move by means of dogs. Some advocate the digging out of rabbits, but others consider this a waste of labour. Pit traps are found useful.

Cyanide fumigation.—There is one means of destruction which has proved itself incomparably the best for dealing with rabbits in bulk. It has the disadvantage that it yields no return for the sale of the rabbits, but on the other hand by means of it rabbits can be effectively destroyed, whereas any attempt to trap out a rabbit population completely would be prohibitively expensive. The method I refer to is the use of cyanide fumigation. A white dust consisting of calcium cyanide or an equivalent substance is pumped into the burrows by means of powerful pumps; reaction with the moisture of the air produces hydrocyanic acid gas, which brings a speedy and humane death to every animal that breathes it. Naturally those who dislike innovations or are interested in preserving rabbits or in the manufacture and use of gin-traps, have sought to discredit this method. They have asserted that it is dangerous to the operator, although, so far as I have been able to find out, nobody has ever been killed in the open air through the use of cyanide fumigants. (Their use indoors is another matter, and deaths have occurred when houses or ships have been fumigated against insects or rats.) Again, it has been alleged that if rabbits which have breathed HCN were to be eaten, the health of the person eating them would suffer; this is untrue, for rabbits have been eaten in this country by way of experiment both by human beings and by dogs, and it has been shown in Germany that the compounds formed in the blood by inhalation of HCN break down into harmless thiocyanates. Moreover, in the fumigation of citrus trees in South Africa it often happens that chickens roosting in the trees are killed by the gas, and these chickens are eagerly sought by the natives, who eat them without suffering any ill effects.

Again, allegations have been made against the humaneness of cyanide fumigation, but in the fumigation of ships it fairly often happens that men receive a sufficient dose of the gas to render them unconscious; these men have to be brought back to consciousness by suitable treatment, and they all declare that the operation was painless. Moreover there are no noticeable after-effects. Very different are the irritant gases, such as sulphur dioxide; a sublethal dose of this gas will certainly cause inflammation of the lungs followed by slow suffocation. Carbon monoxide in the exhaust gas from a motor-car is a useful and humane fumigant under suitable conditions, but both carbon monoxide and sulphur dioxide have the disadvantage that they diffuse into porous soil, whereas the calcium cyanide continues to give off gas for some hours, thus replacing the gas lost by diffusion. Of course, cyanide fumigation must be used with reasonable skill and knowledge, and may in certain circumstances need to be supplemented by shooting, but in combination with dogging it is the ideal method for dealing with the rabbit plague.

Ferreting.—One of the most effective means for use in a highly farmed country like Great Britain is the ferret. Mr. Perkins, of Haverfordwest, Pembrokeshire, has recounted how, when he abandoned trapping and changed over to ferreting, his farm was practically cleared of rabbits in three years, and no damage is now being done to any of his crops. For the previous 28 years he had persisted in close trapping, that is to say, in trapping practically all the year round, and at the end of that time the rabbits had been as bad as ever; in the winter of 1926–7 about 10,000 rabbits had been caught on his farm. The change-over from trapping to ferreting in 1927–8 cured the trouble. Similar experiences have been related by other farmers who hold responsible positions in their districts.

This curious effect is usually attributed to the fact that ferrets, unlike traps, do not kill off the native fauna, some of which are the natural enemies of the rabbit. Another rather interesting theory has, however, been put forward, and it may account in part at least for the known facts. This theory is that the various methods of catching rabbits have a direct effect on the ratio of the sexes present in the population. It will be remembered that Rodier sought to keep down rabbits by releasing the bucks which he caught, and killing the does. Although this method has not achieved any high degree of popularity, it calls attention to the importance of sex ratio in its bearing on the rate of increase of the population. Now, a skilful trapper can catch either bucks or does at pleasure, and it is to his interest to catch bucks, since their skins are graded considerably higher than those of does, and their carcasses are worth more in the market. Moreover, it is possible that there may be an inherent tendency for bucks to be caught in the traps, since they are believed to come out of the holes first in the evening; but few reliable figures are available on this subject, and there is a complication in that more doe rabbits than bucks appear to be born in each litter. On the other hand, it is an undoubted fact that when ferrets are put into the burrows at the end of the trapping season, the number of does caught in this way is enormously greater than the number of bucks. Thus, it seems quite possible that the superiority of ferreting to trapping may be due to the

tendency of the former method to kill off the doe rabbits. However, it would be undesirable to dogmatize on this subject until more definite data are available. In any case, the main reason why the rabbit-trapping industry has been associated with increase in the rabbit population is probably the same as that which accounts for an increase in the cattle-population when dairy farming is introduced. The animals are regarded as stock, to be preserved against poachers and not to be destroyed by any means which prejudices their market value. This is bad husbandry, but many farmers cannot get away from the fact that rabbits give them a cash return.

Virus-poisoning.—The proposal to kill rabbits by means of a virus which could be communicated from one animal to another has attracted agriculturists for many years past, and a number of viruses have been tried. Unfortunately they have never been successful in the field, whatever success they may have obtained in the laboratory and in trials on a small scale. The most recent virus to be tried has been that of *Myxomatosis cuniculi*, for which the highest hopes were at first held out. When tested on Skokholm Island, however, it failed to produce any permanent result. The colonies in which infected rabbits had been released were, indeed, wiped out, but the disease failed to spread from one colony to another. Experiments with this virus are still being made in various parts of the world, and again it would be undesirable to dogmatize too firmly about the results; nevertheless, the prospect of any major success with virus appears to be very small.

Other methods.—In addition to trapping various other methods of taking rabbits for the market are used in Britain, but as a means for keeping down rabbits they do not compare favourably with cyanide fumigation. The wire snare is second only to the trap as regards both the extent to which it is used and its inhumaneness. It is favoured rather by the casual rabbitter than by the full-time trapper working on contract, and is more extensively used in Scotland than in England. It can be greatly improved from the humane point of view by putting a knot in the wire to prevent the noose from running up tight.

The traditional method of the British poacher is the long net—a kind of fishing net 100 yards long held up on short poles and laid at night between the rabbits' feeding-ground and their burrows. The rabbits are driven into this net by means of dogs, and large numbers of them can be caught and killed in a short time. Unfortunately, the method can be used only on favourable ground and in favourable weather.

Another method which has become very popular in some parts of Britain is the spotlight and dog. On a suitable night, a focused beam is turned on a field of rabbits; it is easy to pick out a rabbit by the reflexion from the eyes, and a trained dog, which need not be of any particular breed, is then released, the spotlight being kept on the rabbit during the chase. The dog should be back in less than a minute, and the rabbit can then be quickly killed. It is said to be possible to take the best part of 100 rabbits in an evening by this means, but, again, the ground and the weather must be reasonably favourable, and much smaller catches are common.

Conclusions

To sum up, it may be said that for rabbit-control in Britain we have to rely on cyanide fumigation and dogging for the bulk of the rabbits, supplemented by shooting in special situations; destruction must be carried on simultaneously throughout large areas. Ferreting will be resorted to when a moderate population is to be retained for supplying the local market. The large-scale rabbit-trapping industry must go, in the interests of agriculture as well as of humaneness.

In Australia the solution seems to lie in the progressive reclamation of infested land by cyanide fumigation, the reclaimed land being secured by really rabbit-proof fencing and by destruction of harbour and dogging. In both countries the one essential is concerted action between neighbours, and so the clue to a puzzle which seems at first sight to be essentially a field problem lies really in the law and its administration.

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FACTORS AFFECTING THE POST-NATAL GROWTH OF BROWN LEGHORN CHICKENS

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Introduction.—The definition of the environmental and genetical agencies which may affect the growth processes of an organism at various stages in its life-history is of value in extending knowledge of the fundamental basis of developmental mechanics; and when the material examined is of economic interest the results may have an added importance. Such a problem presented itself when a cursory analysis of data, derived from the recorded observations on the Brown Leghorn flock maintained at the Institute, suggested that a relation subsisted between season and variation in post-natal weights of chickens, and further showed that certain hens produced eggs from which the chickens always grew well, whilst others never had offspring that developed satisfactorily.

As the preliminary examination of the material available allowed no definite conclusions to be drawn with regard to the relative importance of environment and heredity in producing these phenomena, a supplementary series of observations was made, the results of which are embodied in this communication.

Material and Method

The data presented were collected during the year 1937. A pen of 20 hens of different ages (1-, 2-, and 3-year-olds) selected, with the exception of the yearlings, for good hatchability and fertility were mated to a single male and all the eggs laid were incubated. The incubator, an electric 'Petersime', was kept in a warm room thermostatically controlled, so that although temperature fluctuations did occur, the variation was considerably less than that shown by the external atmosphere.

At hatching the chickens were pedigreed and transferred to electrically heated 'Petersime' brooders in the same room; they were reared in these for the first four weeks and were then removed to a larger, electrically heated brooder; the sixth week was spent under similar conditions but in an unheated room. Thus, with the exception of the final week of the period through which they were under observation, temperature conditions relating to a particular time of the year can have had little effect on chicken-growth.

The effects of the minor environmental variables, food, tray, and sex, were considered to be sufficiently randomized, and have been disregarded. Two mashes were fed—one with a higher protein-content than the other—in order to determine if seasonal variation were related to differences in protein-level in the diet.

The chickens were weighed daily for the first 6 days and thereafter at weekly intervals for the remainder of the period of observation, arbitrarily fixed at 6 weeks of age.

As the normally occurring decrease in egg-production during the

winter months would have greatly reduced the number of chickens available at this time, and would have introduced further variables, in that some hens would be providing chickens while others were not, the period during which the work was carried out extended from January to September; this has been arbitrarily divided into 5 seasons which have been kept the same for all the characters studied. The chickens were grouped according to season by referring them to the months in which the eggs producing them were laid.

Results

Weight at six weeks.—This measurement showed a definite cyclic trend in relation to season, which was the same for the chickens fed on either ration. January–February eggs were productive of the heaviest chickens at 6 weeks of age; this weight progressively declined until a minimum was reached in the May–June period, and then rose again until the end of the final season during which observations were made. From the data (Table 1) it is clear that the May–June average chicken-weight is significantly lower than that of either the initial or final period studied.

TABLE 1. *Seasonal Variation in 6-weeks Weight*

Season	*No. of birds*	*Mean weight in gm. (with S.E.)*
1. Jan.–Feb. . .	168	335·5±6·1
2. Mar.–Apr. . .	200	287·2±5·7
3. May–June . .	221	240·6±4·9
4. July . . .	127	255·6±5·8
5. Aug.–Sept. . .	235	290·6±5·2

An examination of the possible sources of variation in weight, viz. season, individuality of the dams, and age of dams, was made according to the method of Snedecor [1], which allows for unequal numbers in the classes. The results show that whereas age of dam was without effect, variance due to dams and to season were significantly greater than that attributed to error.

TABLE 2. *Analysis of Variance in Weight of Chickens at 6 Weeks*

Source of variance	*D.F.*	*Mean square*	*F*	*Significance of F*	
				5 per cent. point	*1 per cent. point*
Season . . .	4	129·55	5·25	2·90	4·17
Dams . . .	5	122·72	4·97	3·13	4·50
Error . . .	19	24·70	..	..	..
Age of dams . .	2	*62·55	2·03	19·40	..
Error . . .	11	127·17	..	..	..

* Variance less than error variance.

Having determined that the season at which eggs are laid influences the 6-weeks weight of chickens developing from them, the next step was

to consider whether the effect of this variable could be located at any particular point in the bird's development. Accordingly, several measurements which may be held to contribute to the final weight attained, may now be considered.

The behaviour of egg-weight and hatching-weight throughout the year has been recorded in another publication [2], and the results need not be considered at this point.

Seasonal variation in rate of growth.—For this part of the study 34 chickens—17 male and 17 female—were selected at random for each of the arbitrary 5 periods (except July), from 5 dams giving progeny with a good average weight at 6 weeks. The growth-rate per cent. per week was computed from Fisher's formula for the measurement of relative growth [3].

The average weekly weight (Table 3) was greatest at the time when the 6-weeks weight was largest; the seasonal variation appears to have a trend similar to that of the latter measurement, though it is less marked, and only the differences between the first and third and the first and fourth seasons are significant.

Coefficients of variability show that variation in growth-rate is always high, but tends to be greater in the summer months. Kempster [4] and Asmundsen and Lerner [5] reported a decrease in chicken growth-rate as the hatching season proceeds from February to April, a trend similar to that found in this study.

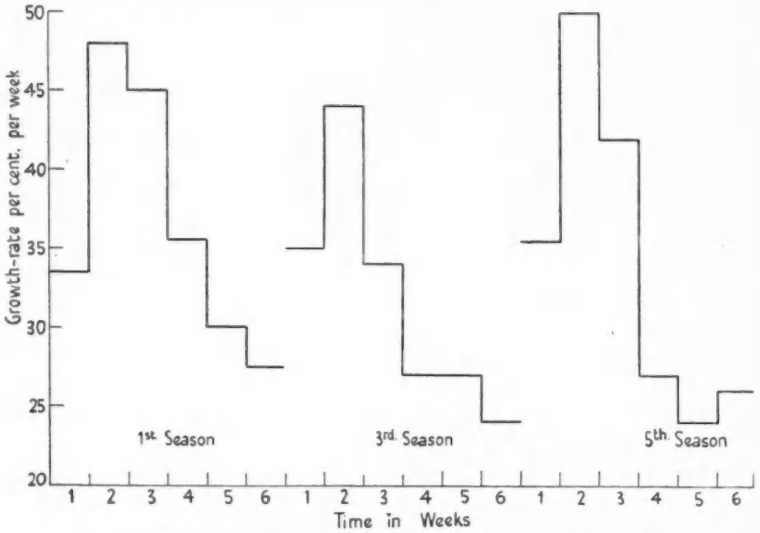
TABLE 3. *Seasonal Variation in Growth-rate of Chickens*

Seasonal groupings	*Birds No.*	*Observations No.*	*Mean relative growth-rate per cent. per week (with S.E.)*	*Coefficient of variability*
1. Jan.–Feb. . .	34	204	36·64±0·86	33·50
2. Mar.–Apr. . .	34	204	34·91±0·80	32·60
3. May–June . .	34	204	31·80±0·90	40·28
4. July . . .	24	144	31·15±1·25	48·15
5. Aug.–Sept. . .	34	204	34·12±0·99	41·55

The behaviour of the individual weekly growth-rates throughout the season is illustrated in Graph 1, which gives curves for the first, third, and fifth periods; the curve for the second period is intermediate between the first and third (as is also the fifth), and the fourth showed the same trend as the third.

The seasonal differences in growth-rate are not distributed evenly over the 6-weeks period, but are concentrated mainly in the third and fourth weeks; maximum rate of growth occurs in the second and third weeks in chickens from eggs laid in the first seasonal group, and only in the second week in those of the third season. In the first 2 weeks there is no significant difference between the percentage growth-rates of chickens of the first and third seasons (first season: 33·50±2·56 and 48·33±1·73; third season: 34·94±1·41 and 44·20±2·00). On the other hand, the percentage rate in the third week was 45·80±1·55 and 34·12±2.35,

respectively, for the two groups, and the difference, 10·88±3·90, was undoubtedly significant, the *t* value being 13·13 with the 1 per cent. value of *t*, 2·57. In the fourth week the respective percentage rates were 35·50±1·37 and 27·00±1·60, giving a significant difference of 8·50±2·97, the *t* value being 11·85 with the 1 per cent. value of *t*, 2·57. In the fifth and sixth weeks the behaviour was the same in all seasons, the differences in rate not being significant.



GRAPH 1. Growth-curves of the 1st, 3rd, and 5th seasons.

Loss of weight after hatching.—Another factor which may be examined, in relation to the variation in 6-weeks weight of chickens, is the extent of the loss in weight normally occurring during the first 24 hours after the chicks have been removed from the incubator and attributable to the rapid assimilation of yolk unabsorbed at the time of hatching. By weighing the chickens at hatching, and again 24 hours later, it was found that the average losses from this cause for the 5 seasonal periods under consideration were: 2·811±0·164, 2·095±0·121, 1·329±0·140, 1·479±0·166, and 1·726±0·116 grams respectively. The number of chickens in the successive periods was 179, 243, 243, 142, and 245. Thus, the trend in loss of weight is similar to that characterizing the 6-weeks chicken-weight; it is highest in the first period, drops in the next two, and rises in the final period. Heywang and Jull [6] find that the loss in weight of the yolk-sac during the 24 hours after removal of the chickens from the incubator is approximately equal to the loss recorded above for the first season. (Hatching-weight is recorded on the twenty-second day of incubation; at this time the chickens are approximately 24 hours old.)

Discussion

As revealed by the analysis of variance, there are two factors which appear to be involved in determining the extent of the variation in the weight of chickens at 6 weeks of age, viz. the individuality of the dam and the time of year in which the eggs were laid. The former influence, probably mainly genetic in origin, can readily be seen when the performance of individual dams is considered. Certain hens consistently gave good chickens throughout the whole period of study, but others never produced good progeny. Jull and Heywang [7] have also noted that progeny of different dams may vary in their rate of yolk-assimilation and attribute this to heritable factors.

With regard to fluctuations within season, the most extreme variations are apparent in the growth-rate in the third and fourth weeks of life. However, it has been shown in an earlier paper [2] that there are also seasonal trends in egg-weight and hatching-weight of chickens, and in the interrelation between the two, which correspond to the seasonal trends both in the weight of birds at 6 weeks of age and the growth-rate up to that stage of development. It is logical, then, to assume that all these factors are similarly affected by some common factor.

Kempster [4] attributes the lower growth-rate in early life of chickens from later hatches (April) to the higher seasonal temperatures at which they develop, but this cannot be regarded as an important factor in the present study since, apart from the final week, the birds were reared under conditions of controlled temperature, the few fluctuations that occurred being relatively small.

In the publication referred to [2], it was concluded that the seasonal changes encountered might reasonably be interpreted as reflections of varying maternal metabolism, the conditioning agent being the thyroid gland. From data on thyroid-weight (which appears to be inversely related to function), it was postulated that the metabolic rate of the dam is low in the first months of the year, rises to a maximum in July, and falls off again in the autumn. On this hypothesis chickens produced in the intermediate seasons would hatch with an inherently higher rate of metabolism than those of the earlier and later ones. Such increases in the metabolic rate should result in smaller growth-increments in the chickens concerned; and this is what occurred.

Further, more rapid yolk-assimilation with a greater resultant post-hatching loss in weight might at first have been expected, although actually the reverse was found. It has to be remembered, however, that differences in metabolic rate in the chickens have been assumed to obtain from the earliest stages in embryogeny, and consequently less unabsorbed yolk should remain at hatching, a point which would explain the inverse trend of the curve. This is brought out by the perceptible differences experienced on handling the chickens: chickens born in summer feel 'stringy', those born in spring are soft and full to the touch.

It is possible that an earlier disappearance of the yolk-sac in summer chickens in the immediate post-hatching period may be in some way responsible for the earlier falling off in the subsequent growth-rate, a

characteristic of all seasons, but particularly marked in the third and fourth weeks of this group. Heywang and Jull [6] report that yolk-absorption is nearly complete by the tenth day from hatching, but further researches are necessary to ascertain the existence of seasonal variations in the rate of yolk-absorption.

The similarity between the curve for seasonal variation in egg-weight and those for measurements taken during subsequent development, suggests that the source of the variation did not arise from the direct impinging of external influences on the chickens themselves, but was due in the main to factors vested in the egg. The extent to which the hypothesis discussed above is capable of accommodating the phenomena observed allows of the further postulation that they are a reflection of forces controlling metabolic processes of the dams.

Summary

1. A study of post-natal growth of Brown Leghorn chickens disclosed two factors of importance in determining the weight attained at 6 weeks of age, viz. season of year and individuality of dam. Age of dam was without significant effect.

2. The weight of chickens at 6 weeks was highest from eggs laid in the beginning of the year and fell to a minimum in May and June, rising again in the autumn. This seasonal variation was demonstrated in the growth-rate and was most marked in the third and fourth weeks of life. Earlier research on this flock of birds had shown a similar trend for egg-weight and hatching-weight of chickens.

3. The loss in weight shown by chickens in the immediate post-hatching period followed the same course, being low in the summer birds and greater in those of earlier and later seasons.

4. It is concluded that seasonal variation in chicken-weight during the period studied does not result from external influences acting during development, but is due mainly to characters vested in the egg which in turn are probably related to factors controlling the physiological activity of the dam.

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THE PLACE OF PLANT PHYSIOLOGY AND OF PLANT-BREEDING IN THE ADVANCEMENT OF BRITISH AGRICULTURE[1]

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In growing any crop the two main biological considerations are which particular variety to use and how to grow it. They respectively link agriculture with plant-breeding and with physiology. The farmer has to take his soil and the weather as he finds them. Some other factors are under his control; and it is by showing how these affect plant-growth that physiology can help crop husbandry.

The discovery that certain elements like calcium, nitrogen, potassium, &c., are essential to plant-growth has been physiology's greatest contribution to agriculture. It has made the use of fertilizers a science. Other practical applications of physiology have been to special cases or crops. But the grand task of husbandry is to meet mankind's enormous needs in wheat, rice, pulses, and other staple foods, in foods for live stock, in fibres, and in vegetable oils. Of the controllable factors of environment by which all these are affected crop-rotation and soil cultivations are the chief.

Grave practical problems.—Rotation of crops is one of the gravest problems of our time; its bearing on the inscrutable question of maintaining soil fertility and humus alone promotes it to supreme importance. The whole of our effective knowledge of rotations and of the role of humus derives from practical farming, not from science. In these great matters we are relying on traditional knowledge, and under the economic stress of our times we, with others, are more and more flouting the old beliefs.

Cultivations are of no less universal interest and of scarcely less obscurity. To lower costs by skimping cultivations has been the resort of some. To intensify them as by ploughing for root crops to 10, 14, or even 20 inches, with the aid of mechanical power, is becoming the fashion among others. Science can offer no more than the comment that deep cultivation might let air into the lower soil and lessen resistance to root-penetration; and so it might increase yield.

Experiment or tradition.—The new science of crop husbandry, by its cunning technique of field plots, is able to measure the effect of variations in crop-rotation or cultivation on yield. Such measurements alone achieve little. The secret of the whole matter is how the differences in yield are brought about, and only the living plant can reveal this. It is therefore imperative to put new life into field experiments, to interpret them physiologically. This involves demonstration of the way in which variations in agricultural practice affect the stages and aspects of the plant's growth. The 'developmental observations' (as they may be

[1] Contribution to a symposium on Practical Problems of Crop Production, British Association for the Advancement of Science, Section M (Agriculture), August 22, 1938.

called) which so far have come into use are crude, being the simple counting of stems or other organs, measurements of the area of leaves, or of the weight of the plant at regular intervals of time. Their use has, however, already led to certain small improvements in agricultural practice. The labour of more searching studies would only be warranted if physiology could so design them as to show analytically the influence of husbandry methods on plant-growth. More knowledge of the root-system and its work ranks high among specific requirements.

The task of physiology in agriculture.—Physiology, or any other pure science, cannot be asked to solve farming problems. On the applied side, however, its great task is to equip the experimenter in husbandry with tests or indices, the simpler the better, of plant-growth and its relation to final yield. This task persists in altered form in plant-breeding, the other branch of science with which this paper deals.

Illusions about breeding.—Plant-breeding has gained from genetics new confidence, analytical grasp, and wider horizon; but it remains, despite the common illusion, a blend of art and empiricism. The range of its successes has greatly widened in the past few years, especially in herbage plants and in crops amenable to vegetative propagation. With both of these genetic understanding of self-sterility and cross-compatibility has illuminated practical procedure. In general, however, genetics has not fundamentally improved breeding-methods.

The objective in breeding.—The objective in breeding is to produce better varieties, i.e. objectives which enable the farmer to get a higher net cash return than existing varieties give. It imposes a stern test on the breeder's work: but it is the test. Higher yield, better quality, and better field-characters (as in the non-lodging of cereals) are the essentials of betterment.

The farmer's part.—In farmers, common human expectation of the miraculous, inflamed by ill-informed publicity, has created the belief of a magic in plant-breeding. It may be simple, in primitive agriculture, to raise new varieties which greatly increase the farmer's returns without increasing his effort; but in most British crops, past improvements have greatly narrowed the chances of new progress. Thus the new short-strawed wheats enable very heavy crops to be grown without lodging if the level of husbandry be high. They do not and cannot extract from poor land, farmed low, any greater yield than the best suited of the existing varieties. In short, under British conditions, breeding can help to raise the level of husbandry and output, but it cannot, in general, lessen the farmer's task in maintaining it.

The consumer's part.—The farmer may be expected to spare no pains in choosing the variety best suited to his circumstances for yield and for field characters. But can he be expected to be highly critical about quality of produce? No one can blame him for asking what quality is worth—to him, not to the consumer. The fact is that quality of farm produce is a favourite subject for indulgence in humbug. The intermediary and distributor often mean better grading, preparation, and packing when they speak of better quality. If farmers are to raise the level of true (biological) quality the breeder must make new varieties for

them. This will be impossible unless quality in the several crops is suitably defined, and perhaps impolitic, unless it is to be recognized in price. What consuming industry persistently fails to understand is that, basically, quality is a varietal characteristic, and that fair and rational buying of crop products should be based on ascertainment and common recognition of varietal merit. Soil, manuring, and husbandry also influence quality, though they cannot prevail against any but small varietal differences. Specific problems of policy and method in breeding may now be considered.

Nature of crop characters.—That by successive hybridizations a large array of desirable characters may be united into a single, new, ideal variety, it may be of wheat, by a direct, simple, orderly synthesis is the illusion of some scientists and publicists. To the plant-breeder it is an oft-recurring dream, which does not come true because commercial plant-characters like yield and quality are of awful complexity. They are integrations of the results of many vital processes, the processes themselves being controlled, it is safe to say, each by many Mendelian factors or genes. Optimistic talk about the inheritance of such a thing as 'yielding capacity' fails to understand that, with existing knowledge, a lifetime of work would not resolve the problem. Yet, to make breeding scientific, these obscure commercial characters must be analysed. In this task another great field of endeavour is opened up to plant physiology. Meantime the breeder must help himself. Yield, quality, drought-resistance, and characters of similar importance must be assessed in the primary stages of breeding, when selection for larger-scale trial is being made from among thousands of potential new varieties, of each of which, necessarily, only a very small bulk is available. Empirical small-scale tests (as of physical characters of wheat doughs) and observation of 'associated characters' (as of tillering with winter cereals) have proved helpful in this matter. A great development of them is one of the outstanding needs of plant-breeding.

World exploration.—By the act of hybridizing the breeder can take out, in the form of a new variety, no more than he puts in. That is, though he makes new combinations of the true Mendelian unit characters of the parents he uses, he cannot create new unit characters. To solve a practical problem he often needs a character—perhaps resistance to some disease—not to be found in any known variety. In certain cases spectacular changes in plant-characters have been brought about by X-radiation or chemical means. Such 'induced mutations' may ultimately help the breeder, but his present hope is in collecting all possible varieties of the crop concerned from all parts of the world. In some new and perhaps otherwise unattractive variety he may find the character he needs. Great Britain is behind at least three other countries in its facilities for economic plant-exploration.

Genetic problems in breeding.—In breeding-methods certain primarily genetic problems are urgent. There is rigid insistence on very high uniformity of type in wheat, barley, oat, pea, and bean varieties—crops which are almost rigidly self-fertilizing. Is the highest attainable uniformity in morphological characters in a new cereal variety, of hybrid origin,

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of any commercial advantage? And if not, what limits for uniformity should be set? Again, with varieties like Spratt-Archer barley, Resistance oats, Yeoman, Little Joss, and Holdfast wheats (all produced by hybridization), recognizably different sub-types become observable after a few years in general cultivation. Do they result from segregation or from mutation? If from the latter, can non-mutating sub-types be found? And is the great labour of isolating sub-types repayable in commercial advantage?

Out-pollinating crops.—Many grasses, the clovers, beet, and other common root crops, Brussels sprouts, cabbages, kales, and other *Brassicae*, onions, and many other vegetables, are naturally out- or cross-pollinating. Some are, in addition, largely or wholly self-sterile. Thus, a single plant being unable to fertilize itself, at least two plants must be used to start a new seed-stock. As multiplication goes on, inevitable inter-pollination completely precludes the high uniformity obtainable (as pure lines) in cereals. By great patience and art, uniformity can be maintained at a fairly high level, and the commercial advantage of this is very evident in the best varieties of Brussels sprouts, in which perhaps only 10 per cent. of the plants in a field are 'blowers' (loose, unmarketable sprouts) in contrast with 20, or even 30 per cent. in imperfectly bred stocks. There are in several normally out-fertilizing crops known types which are self-pollinating. They may give uniform progeny but fail in vigour, a result only attributable at present to the mysterious phenomenon known as 'hybrid-vigour'. Genetics could greatly help the breeder, and advance science as well, by discovering the nature of the phenomenon.

The practical breeding-procedure with an out-pollinating crop is, by inexhaustible patience, to identify certain 'types'—it may be six or so—which, when allowed to inter-pollinate, give a reasonably uniform bulk-variety of commercial merit. The laborious rebuilding of the bulk-variety has to be carried out afresh every few years to preserve comparative uniformity. The merits of such a production depend partly on the combination of desirable Mendelian characters and partly, it must be supposed, on hybrid-vigour. Which particular characters, in any case, are primarily important and which initial types, when inter-crossed, most promote hybrid-vigour are questions not even amenable to useful speculation. To set breeding-methods for cross-pollinating plants on an orderly basis, without asking as yet for a truly scientific basis, is one of the grand problems of plant-breeding. At present our distinguished breeders of such crops work primarily by art. They cannot give the art to others; they cannot, such is the complexity of commercial plant-characters, even describe fully the criteria they adopt.

The cross-breeding of widely different parents (inter-species crosses), though highly intriguing, offers breeders of most crops at present limited possibilities and occasions no immediate major problems so far as British crops are concerned.

Breeding and national policy.—It takes thirteen to fifteen years to make and launch into cultivation a new hybrid English cereal variety. Plant-breeding must therefore have a long-term policy. How easily this may

be upset by the instability of our agricultural situation is well shown by wheat. Thirty years ago there was begun, at the instigation of the millers, a campaign for growing high baking-quality wheat in England. The advantages, for inland mills, were evident. Yeoman wheat, produced by Biffen in 1916, brought us within range of the all-English loaf. But millers were slow to pay a premium for its fine quality; then inland mills began to be closed down on a plan of rationalization; world wheat-supply vastly increased under war-stimulus; and home egg-production became so great and prosperous as to induce millers to leave English wheat to the chickens, using overseas in its place. But more new hybrid wheats were in the making, and one, Holdfast, proved a substantial advance on Yeoman in bread-quality. It came to a market unconcerned about quality in English wheat. Fortunately Yeoman and Holdfast have yield and standing-power which, apart from baking quality, make them good farmers' wheats. In the past two years disastrous prices and prospects for egg-production have drawn millers back to English wheats, and they once more show an interest in their quality.

Breeding-policy.—Long-term breeding-policy must be based on the relative national importance of the different crops and on their amenability to improvement. The latter characteristic can be gauged by the breeder though, as wheat shows, the economic range of improvement by new varieties depends on general agricultural trends. But the relative national importance of different crops is highly speculative. Take mangolds, swedes, turnips, kale, peas, and beans, all of which have sharply declined in acreage since 1914. Their future place in our farming depends on the extent to which beef, mutton, and milk are to be produced off arable land or off grass. And this question is perhaps as big as any in the future of our farming policy. It interlocks with many others which interest breeders, bearing for instance on cereals in the matter of straw, and, of course, on grasses. Other similar problems abound. Is sugar-beet to be a permanent British crop? On what scale? And is home-production of seed with the production of special British varieties a matter for the breeder to take up?

The great tasks of plant-breeding are to find for its methods a scientific basis, and for its long-term policy a greater assurance.

MANGANESE DEFICIENCIES IN CROPS

I. SPRAYING PEA CROPS WITH SOLUTIONS OF MANGANESE SALTS TO ELIMINATE MARSH SPOT

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Introduction.—In 1936 Pethybridge [1] pointed out that Marsh Spot in peas might be due to deficiency of manganese. Experiments by Koopman [2] in Holland have confirmed that Marsh Spot can be greatly reduced by spraying the crops with a 1 per cent. solution of manganese sulphate, and Ovinge [3], also working in Holland, has shown that manganese sulphate applied to the soil reduced Marsh Spot, but the amount of manganese sulphate required was large (1–2 cwt. per acre).

Manganese-deficiency in crops usually occurs on soils which have the power to lock up added manganese in an unavailable form. Hence, relatively large amounts of manganese salts must be applied to overcome the deficiency. The facts that manganese salts are expensive, and that they are likely to have little residual value on such soils, render very difficult the position of farmers who have land which is either naturally deficient in available manganese or has been made so by over-liming.

Although the cost of remedying the deficiency could be reduced by applying manganese to the soil at the time when it is most needed by the crop, a more logical line of approach is to try to get manganese into the crop by other means than via the soil. Spraying the foliage with a solution of a manganese salt (as tried by Koopman [2]) is the most obvious practical possibility. This paper describes experiments to test the relative merits of these two methods of applying manganese. The experiments were conducted in one year only, but spraying seems so promising that the results are presented in the hope that farmers growing peas on soils where Marsh Spot occurs will test spraying on a practical scale.

Experimental

Three field experiments were conducted in 1938 on peas in Romney Marsh on areas where Marsh Spot was known to occur. Since the pea crop shows no external symptoms and the disease affects the seed only, it appeared that applications of manganese late in the life of the plant might be most effective.

It was intended to use manganous sulphate ($MnSO_4$) in the experiments, but as they had to be laid down at short notice and a supply of manganous chloride ($MnCl_2$) was on hand, the latter material was used. The sulphate is rather less hygroscopic than the chloride, and it is less likely to cause damage to plants if used in too high a concentration, so that for practical purposes the sulphate is to be preferred.

The sprays were applied at 100 gallons per acre by means of a small hand-sprayer producing a fairly fine mist. A proprietary wetting agent, 'Lissapol L', was added at the rate of 0·1 per cent. by weight to the spray

liquid. 'Lissapol L' gives no precipitate with manganous chloride or sulphate in the cold at the concentrations used.

The percentage of seed affected by Marsh Spot was determined by examining 400 seeds per plot in all the experiments.

Experiment I. Newchurch.—The peas (variety unknown) were about one to two inches through the ground on April 27, when the soil treatments were applied in bands about 2 in. wide immediately at the sides of the rows. On June 10 the plants were 15–18 in. high and were in flower. The plants were in pod on June 30. The weather was sunny when the sprays were applied.

TABLE 1. *Centre: Newchurch*

	Application			*Marsh Spot*		*Yield of pods*
Treatment	*Rate lb. per acre*	*Method*	*Date*	*Per cent.*	$\sin^{-1}\sqrt{x}$	*Per cent. of control*
1 & 12 nil				65·3	0·954	100
2 $MnCl_2$	500	To soil	April 27	22·5	0·478	104
3 ,,	100	,, ,,	,, 27	36·5	0·648	121
4 ,,	20	,, ,,	,, 27	70·3	1·043	105
5 ,,	10	,, ,,	,, 27	52·0	0·808	95
6 ,,	10	Spray	June 10	4·5	0·185	99
7 ,,	10	,,	,, 30	17·8	0·408	77
8 ,,	10+10	,,	,, 10 & 30	6·0	0·190	108
9 ,,	20	,,	,, 10	2·5	0·080	91
10 ,,	20	To soil	,, 10	28·5	0·545	99
11 ,,	100	,, ,,	,, 10	11·0	0·330	102
			Standard error of mean of 4		0·0955	9·5

The results show quite clearly that spraying gave by far the best results. The spray was much more effective if applied when the plants were in flower than when they were in pod. The difference between the effects of 10 and 20 lb. manganous chloride per acre applied as spray when the plants were in flower was insignificant.

The yields of pods show no significant differences from the control.

Rainfall at Lympe, which is fairly near Newchurch, was as follows:

	1938 (inches)	*Average (inches)*
April . .	0·51	1·68
May . .	3·33	1·18
June . .	1·46	1·93
July . .	2·44	2·13

The weather after the first spraying was drier, and that after the second spraying rather wetter, than normal. The differences from normal were, however, not great. On July 5, five days after the second spraying, there was a fairly heavy fall of rain (0·65 in.), and it might appear that this contributed to the smaller reduction of Marsh Spot with the late spray than with the earlier spray. The results of the experiment at Lydd, where the rainfall was very similar, refute this assumption.

Experiment II. Lydd.—The soil applications were made by mixing the

manganese salt with a little soil and sowing directly on the seed (variety Onward) in the drills on April 28. The plants were 6–9 in. high at the first spraying and were in flower at the second spraying.

Examination of the plots on June 10 showed that 200 lb. manganous chloride per acre applied to the soil had reduced the stand of plant and early growth.

TABLE 2. *Centre: Lydd*

	Application			*Marsh Spot*		*Yield of pods*
Treatment	*Rate lb. per acre*	*Method*	*Date*	*Per cent.*	$\sin^{-1}\sqrt{x}$	*Per cent. of control*
1 & 5 nil				47·5	0·7635	100
2 $MnCl_2$	5	Spray	June 10	49·5	0·785	141
3 ,,	10	,,	,, 10	40·0	0·685	181
4 ,,	20	,,	,, 10	46·0	0·75	138
6 ,,	5	,,	,, 30	3·0	0·17	134
7 ,,	10	,,	,, 30	6·0	0·25	158
8 ,,	20	,,	,, 30	7·5	0·27	139
9 ,,	40	To soil	April 28	60·5	0·895	117
10 ,,	200	,, ,,	,, 28	40·5	0·69	71
			Standard error of mean of 2		0·0643	12·4

The early applications to soil had no effect on percentage Marsh Spot. The spray had no effect when applied before flowering, but was effective when applied when the plants were in flower. There was no significant difference between the rates of application of the sprays.

The spray treatments increased the yield significantly. The low yield when 200 lb. manganous chloride per acre was applied was due to the reduction in stand of plant mentioned above.

Rainfall at Dungeness, which is fairly near Lydd, was as follows:

	1938 (inches)	*Average (inches)*
April . .	0·59	1·38
May . .	2·01	1·30
June . .	0·59	1·58
July . .	1·48	1·74

As at Newchurch, the weather after the first spraying was drier, and that after the second spraying rather wetter, than average. On July 7, seven days after the second spraying, there was a fairly heavy fall of rain (0·47 in.). Despite this, the second spray was very much more effective than the first one.

Experiment III. Ruckinge.—As in the experiment at Lydd, the applications to soil were made by mixing the chemicals with a little soil and sowing directly on the seed (variety Onward) in the drills on April 29. The plants were about 9 in. high when sprayed; they were not in flower.

Examination of the plots on June 10 showed that applying 200 lb. of manganous chloride per acre had retarded growth and killed some seedlings.

The heavy dressings of manganous chloride (200 lb. per acre) and of potassium permanganate significantly reduced the percentage Marsh

Spot, the effect of the former being significantly greater than that of the latter. The spray, which was applied *before the plants were in flower*, had no effect on Marsh Spot. The small dressing of manganous chloride to the soil was also ineffective. None of the differences in yield is significant. Ruckinge, like Newchurch, is fairly near Lympne, so the rainfall figures given on p. 151 are applicable.

TABLE 3. *Centre: Ruckinge*

	Application			*Marsh Spot*		*Yield of pods*
Treatment	*Rate lb. per acre*	*Method*	*Date*	*Per cent.*	$\sin^{-1}\sqrt{x}$	*Per cent. of control*
Nil				51·8	0·815	100
$MnCl_2$	200	To soil	April 27	11·8	0·333	119
,,	20	,, ,,	,, 27	44·0	0·730	86
,,	10	Spray	June 10	51·5	0·815	100
$KMnO_4$	250	To soil	April 27	29·3	0·568	106
			Standard error of mean of 4		0·0796	13·8

Discussion

Percentage Marsh Spot.—The results show clearly that spraying the crop when in flower with a solution supplying 5–20 lb. manganous chloride per acre was much more effective in reducing Marsh Spot than applying considerably greater amounts to the soil.

Time of application was important for spraying and for soil dressings. Manganese gave better results when applied to the soil when the crop was in flower than if applied at seeding time. Ovinge [3], working in Holland, also found that manganous sulphate (89 lb. per acre) was much more effective if applied to the soil before or after flowering than when applied earlier. It seems clear, however, that even if applied at flowering time, more than 100 lb. per acre of manganous sulphate would be required.

Spraying was much more effective if carried out when the crop was in flower than if carried out earlier or later:

Percentage Marsh Spot

When sprayed	*Newchurch*	*Lydd*	*Ruckinge*
No spray	65·3	47·5	51·8
Before flowering*	..	40·0	51·5
In flower*	4·5	6·0	..
In pod*	17·8	..	..

* 10 lb. $MnCl_2$ per acre.

Koopman [2] has also found that spraying at the end of flowering and again three weeks later with 1 per cent. $MnSO_4$ solution (no wetting agent added) was effective.

Spraying reduced the incidence of Marsh Spot from 50–60 per cent. to about 5 per cent. Failure to eliminate Marsh Spot entirely was possibly due to the sprays not covering all parts of all plants. The incidence of Marsh Spot might, thus, be reduced to zero if the plants

were sprayed twice when in flower. Whether the extra value of the crop would pay for the labour involved is, however, a matter of doubt. There is no evidence that increasing the amount of $MnCl_2$ above 20 lb. per acre would be an advantage; 5–10 lb. per acre may, in fact, be adequate.

It is hoped that farmers who grow peas on soils where Marsh Spot occurs will test on a practical scale the effect of spraying and, for those desirous of so doing, the following tentative recommendations are made:

Per acre at each spraying

Spraying once when in flower

24 lb. anhydrous manganous sulphate ($MnSO_4$) or 36 lb. hydrated manganous sulphate ($MnSO_4 . 4H_2O$) in 100 gallons of water plus a suitable wetting agent (e.g. 1 lb. Lissapol L per 100 gallons).

Spraying twice when in flower

12 lb. $MnSO_4$ or 18 lb. $MnSO_4 . 4H_2O$ in 100 gallons of water plus wetting agent.

Yield.—In one of the three experiments, yields were apparently increased by spraying. In contrast to the importance of time of spraying on percentage Marsh Spot, the yields in this experiment were increased as much by spraying some time before flowering as by spraying at flowering time. Koopman [2] also thought that yields were increased since the 1,000-seed weight was increased. The whole problem of the effect of manganese compounds on yield obviously needs further study.

Summary

The results of three field experiments show that heavy dressings of a soluble manganese salt, when applied to the soil at sowing time, had very little effect on the incidence of Marsh Spot in peas. If applied later to the soil, when the plants were in flower, manganese was more effective. Spraying the foliage at flowering time with solutions of a manganese salt gave, however, a much better control of Marsh Spot.

Time of spraying was of fundamental importance. Spraying was much more effective if carried out at flowering time than if carried out earlier or later.

The results suggest that manganese may sometimes increase yields.

Acknowledgements

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TIME OF APPLICATION OF NITROGEN AS A FACTOR INFLUENCING THE YIELD OF HERBAGE ON PERMANENT PASTURE

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INTEREST in the intensive use of nitrogen on grassland has greatly increased in recent years, and is being stimulated through the use of the herbage so produced either for grass-drying or for intensive grazing.

In view of the large amounts of soluble nitrogenous fertilizers that are normally applied for such purposes, it was thought that there was a risk of loss of nitrogen by leaching under the high rainfall in the west of Scotland. It was decided, therefore, to test the effects of the application of equivalent amounts of nitrogen in a single heavy dressing at the beginning of the growing-season and in two dressings at different times during that season. Woodman, Evans, and Oosthuizen [1], in work published since this experiment was begun, showed that at Cambridge a single heavy dressing of sulphate of ammonia, provided that it did not scorch the herbage, gave yields as great as a similar amount of sulphate of ammonia applied in small dressings during the growing-season.

With this object in view a replicated experiment was carried out in 1937 and 1938 on the College Experimental Farm at Auchincruive, using nitrate of soda as the source of nitrogen.

The Experiment

The experiment was laid down on old permanent pasture in Temple Park, Auchincruive. Previous experiments had shown that the herbage in this field responded readily to applications of nitrogenous fertilizers. Prior to the start of the experiment—in April 1937—the area used for the plots had been enclosed from stock for three years, and had been cut twice annually during this period, no manures having been applied during this interval.

The soil was a light loam, distinctly acid, and carrying herbage of rather a poor type, consisting chiefly of *Agrostis* and fine-leaved fescues with only a very little wild white clover.

The experimental plots were laid out in a 4×4 Latin square, each plot being 10×25 links, i.e. 1/400 acre. The four different treatments used, each replicated four times, were as follows:

Treatment no.	*Treatment*
1	No nitrogen
2	2 cwt. per acre nitrate of soda in April, and 1 cwt. per acre in July
3	2 cwt. per acre nitrate of soda in May and 1 cwt. per acre in August
4	3 cwt. per acre nitrate of soda in April

The nitrate of soda used was the granular form and contained 16·0 per cent. of nitrogen.

The time-table of operations was as follows:

	1937	*1938*
Nitrogen applied (Treatments 2 and 4)	April 9	April 1
First cut and nitrogen applied (Treatment 3)	May 14	May 18
Second cut	June 17	June 17
Third cut and nitrogen applied (Treatment 2)	July 20	July 26
Fourth cut and nitrogen applied (Treatment 3)	August 17	August 29
Fifth cut	October 7	October 28

The longer period between the application of the nitrate of soda and the first cut in 1938, as compared with 1937, was due to the drought in April and early May. The amount of growth by May 1 was not sufficient to allow of cutting with the scythe, so that cutting had to be delayed until May 18. Also the rainfall in October was so great that cutting could not be carried out until the 28th. This, however, should have little effect on the comparison for the two years as growth during October was slow on account of the short period of daylight and low temperature.

The grass was cut by scythe, collected, and weighed immediately. A representative sample from each plot was taken at the same time for the determination of dry matter. All yields were calculated on a basis of the dry matter so as to overcome the difficulty of comparing yields of material with a variable moisture-content. The dried samples were retained for analysis.

Results and Conclusions

A summary of the yields obtained is given in Table 1; it includes the yield obtained at each of the five cuts and also the total yield for the season from each treatment.

TABLE 1. *Yields of Dry Matter in lb. per acre*

1937

Treatment	*1st cut*	*2nd cut*	*3rd cut*	*4th cut*	*5th cut*	*Total*
1	435	985	642	959	559	3,580
2	966	1,301	633	1,272	618	4,790
3	381	1,867	719	934	809	4,710
4	1,065	1,573	633	1,055	603	4,929
S.E.	154	156	58·4	109	74·0	268

1938

1	567	651	829	847	566	3,460
2	883	935	875	1,179	593	4,465
3	568	1,144	1,119	893	798	4,522
4	1,117	1,054	971	960	557	4,659
S.E.	111	61·2	91·0	110	71·2	284

The Table shows that there was a very marked and significant increase in yield due to the application of nitrogen. The response was rapid, as in every case where nitrogen has been applied there was a significant increase in yield at the following cut. The effect was, however, not very prolonged and in practically every case was significant only for the first two cuts after application; Treatment 4, with the heavier

dressing of nitrate of soda, was the exception. Yields obtained in the first cut in 1938 showed that the nitrogen applied in 1937 to plots used for Treatment 3 had no effect after the winter:

Treatment	*Yield 1st cut, 1938*
1	567 lb. dry matter per acre
3	568 ,, ,,

The total yields for the different treatments, both in 1937 and in 1938, showed that, although there was a very highly significant increase obtained with an application of 3 cwt. of nitrate of soda, time of application made no significant difference. Taking the yield of the control plots as 100, the yield for all the plots receiving nitrogen was 134·4 in 1937 and 131·5 in 1938, showing that there was a very close correlation in response to nitrogen in the two seasons.

As there were marked differences between the yield obtained at the different cuts over the two seasons, these are compared graphically with the rainfall in Figs. 1 and 2, the yields from the control plots being used for this comparison.

It will be seen that the growth-curves for the two seasons are very different. In 1937 there were two very distinct periods of rapid growth, as shown by the high yields obtained in June and August. This type of growth-curve appears to be normal: maximum growth in May and June and a secondary peak in August. Similar results were obtained by Woodman, Blunt, and Stewart [2] at Cambridge, and also by Watson, Procter, and Ferguson [3] at Jealott's Hill. Woodman and his co-workers were able to show that the growth-curve for pasture followed fairly closely the rainfall curve; this cannot be shown for the experiment under consideration, owing to the longer interval between the successive cuts, monthly as compared with weekly. The very low yield obtained for the July cut is, however, explicable: there was a dry period from the end of the first week in June to the end of the month, and the heavy rains at the beginning of July were not in time to allow of any considerable growth before the cut at the middle of July.

In 1938 the growth-curve was of a totally different type, the yield gradually rising to a maximum in August. This was probably due to the early flush period in May and June being suppressed by the long dry period during April and the first half of May.

TABLE 2. *Monthly Rainfall (inches) during 1937 and 1938*

	1937	*1938*
January	4·31	5·11
February	4·40	1·28
March	0·83	2·30
April	1·66	0·38
May	1·23	2·42
June	2·39	4·31
July	5·19	4·31
August	2·31	2·97
September	1·99	3·28
October	3·29	7·86
November	0·33	5·31
December	2·20	2·16

The Table illustrates the more uniform distribution of rainfall in 1938 after the initial dry period in April and May as compared with the irregular distribution that occurred in 1937.

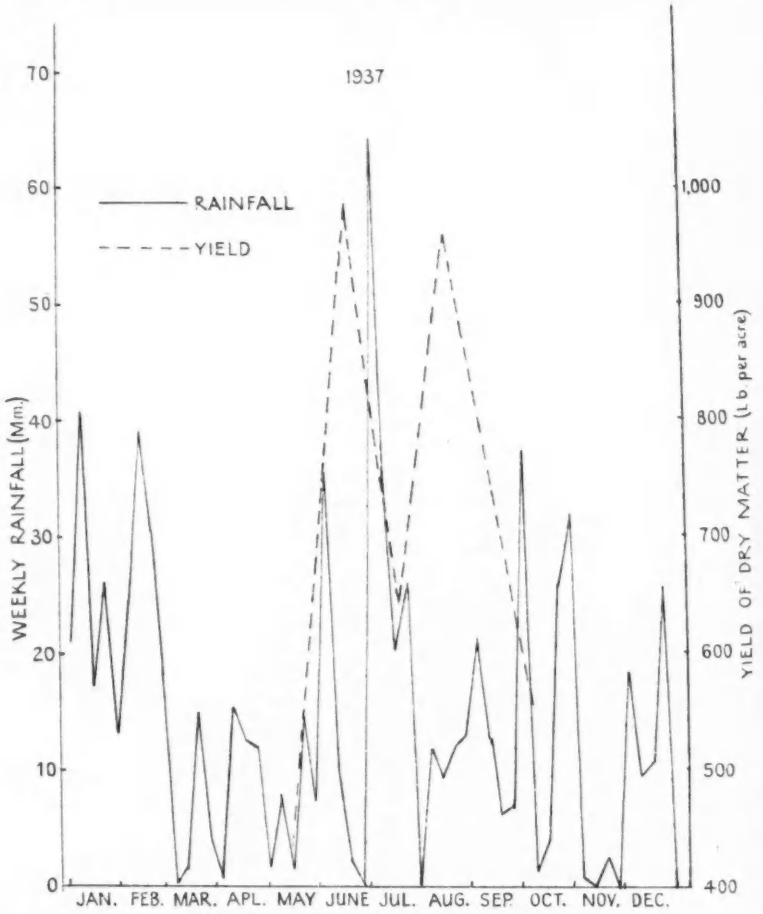

FIG. 1. Weekly rainfall and yield of dry matter in 1937.

Nitrogen recovery.—To determine the amount of nitrogen that was recovered in the crop, a composite sample was made from all the cuts of each treatment and the total nitrogen in this sample was determined. The results are given in Table 3.

In both seasons there was a slight increase in the nitrogen-content of the herbage on the plots that received nitrogen as compared with the control plots; it is, however, impossible to say from the data available whether this difference was significant or not.

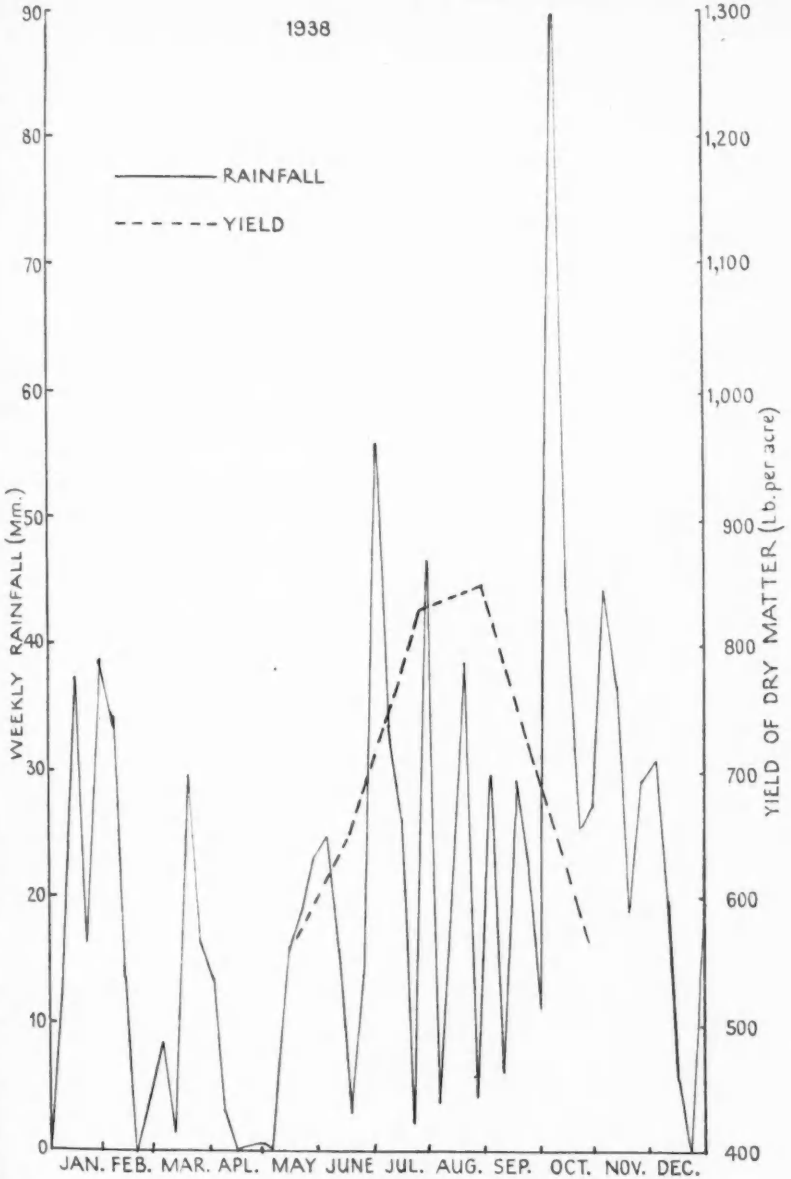

FIG. 2. Weekly rainfall and yield of dry matter in 1938.

The percentage recovery of nitrogen was high considering the rather poor quality of the herbage on the plots. It was slightly higher in 1937, due to the greater yield of herbage and not to the higher percentage of nitrogen in the herbage. The figures show that the nitrogen-content of the herbage was only slightly increased by the application of nitrogen, and therefore the recovery of nitrogen was due to the increased yield of dry matter on the manured plots rather than to an increased nitrogen-content of the herbage. The percentage recovery was highest when all

TABLE 3. *Recovery of Nitrogen in Treatments 2, 3, and 4*

Nitrogen applied 53·8 lb. per acre in each season

	1937				1938			
Treatment	*N per cent.*	*N in crop*	*Increase of N*	*Recovery per cent.*	*N per cent.*	*N in crop*	*Increase of N*	*Recovery per cent.*
		lb.	lb.			lb.	lb.	
1	2·11	75·6	..	..	2·16	74·8	..	..
2	2·35	112·6	37·0	68·8	2·38	106·3	31·5	58·5
3	2·26	106·4	30·8	57·3	2·30	104·0	29·2	54·3
4	2·44	120·3	44·7	83·1	2·38	110·9	36·1	67·1

the nitrogen was applied in April and lowest when applied in May and August, probably because the early application gave a greater yield of herbage grown in the early flush, which is richer in protein than herbage grown later in the season. Woodman and Underwood [4] found that for good quality grassland cut at monthly intervals, there was a recovery of 26 per cent., but in this case there was only a slight increase in yield, probably because a large reserve of available nitrogen was present in the soil and the application of further amounts had little effect on growth.

On the other hand, recoveries of over 100 per cent. have been recorded, notably 179 per cent. by Watson, Procter, and Ferguson [3], but their plots were being grazed by sheep, and large amounts of the nitrogen derived from the herbage were therefore being returned to the soil in the excreta.

The loss of nitrogen by the soil during the course of the present experiment must have been considerable, even on the manured plots, because the difference between the amount added in the manure and the amount removed in the crop was 59·3 lb. per acre in 1937 and 53·3 lb. per acre in 1938. This loss would not have occurred if the plots had been grazed, as then there would have been sufficient nitrogen in the excreta to make up for this loss. Collins [5] states that 96 per cent. of the nitrogen ingested by sheep is returned to the soil in the excreta. On the other hand this drain on the fertility of the soil would have taken place if the herbage had been mown for grass-drying. Little nitrogen could have been fixed from the air, as the amount of clover present in the sward was negligible, so that this very considerable amount of nitrogen would have to come from reserves in the soil.

Summary

1. Application of nitrogen gave an immediate and significant increase in yield.

2. The time of application of nitrogen made no significant difference to the yields of herbage obtained.

3. The yields obtained appeared to be affected considerably by the rainfall, but the intervals between cutting were too long to allow of complete correlation.

4. The percentage recovery of nitrogen was high, varying from 54 to 83 per cent.

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INVESTIGATIONS ON THE WATERING OF CROPS AND GRASS IN TEMPERATE CLIMATES: A DIGEST OF RECENT WORK

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THERE are two aspects of watering, (*a*) emergency watering in times of drought, and (*b*) watering under conditions of normal seasonal rainfall. Under (*a*), where whole crops may be saved by a timely application of water, there is no doubt that watering is profitable. On this principle, successful market-gardeners in England,[1] Germany,[2] and America[3] have installed overhead sprinkling-equipment as a necessary insurance against the effect of dry spells, particularly in the spring. Although cost figures are not published, it is clear that watering vegetables is an economic proposition. Water-equipment is described by Secrett,[1] by Victor,[4] and by the Lanninger-Regner Company.[5] Under (*b*) there is the more complex problem whether economic increases in yields of lower-priced arable crops and grassland products can be obtained by watering. More attention has been paid to irrigating grassland than arable, although the mixed grass sward presents more difficulty than the straight arable crop. The reasons probably lie in attempts to flatten out the pasture-productivity curve and to obtain better utilization of mid-season dressings of nitrogenous and phosphatic fertilizers.

Brouwer[6] reviews literature on the principles of watering. He concludes that uniformity of distribution of artificial rain is considerably below that of natural rain, that current theories to determine the basis of watering are inadequate, that artificial rain is rather less efficient than natural rain, partly because of soil cooling which may be adverse for some crops, and that the precise water-requirement of plants is not exactly understood. If irrigation is to be economic, water must be applied at a period when the plant responds best. Brouwer terms this period the 'critical' period, and shows that, under normal climatic conditions, it synchronizes usually with the period of relatively intensive nutrient-uptake.

Arable Land

Wheat.—Experimental evidence on irrigating arable crops has been summarized by Brouwer (loc. cit.). Autumn wheat on loam was watered by Martiny[7] in 1925. Natural rainfall measured on the field was 43·0 mm. in April, 17·5 mm. in May, 45·0 mm. in June, 39·5 mm. in July, and 115·5 mm. in August. The wheat was watered once at the beginning of June to supply 22·5 mm. water; the increase was 15·83 dz. grain and

[1] *J. Roy. Hort. Soc.*, 1935, **60**, 294–303.
[2] *Reichskuratorium f. Technik in der Landwirtschaft* (*R.K.T.L.*), Schrift No. 30, 1932, p. 101.
[3] *Agric. Engineering*, 1937, **18**, 165–6, 170.
[4] *R.K.T.L.*, Schrift No. 13, 1930, p. 28.
[5] *Beregnungstechnik zur Sicherung der Volksernährung unter besonderer Berücksichtigung der Abwasserverwertung*, Verlag August Weisbrod, G.m.b.H., Frankfurt, 1938.
[6] *R.K.T.L.*, Schrift No. 49, 1936.
[7] *Arbeiten der D.L.G.*, Heft 354.

42·32 dz. straw per ha.,[1] or, 1 mm. of artificial rain[2] improved the yield by 70·3 kg. grain and 188 kg. straw per hectare.[3] If, therefore, water is applied before shooting, i.e. in a period of active nutrient-uptake, a single watering appears to be very profitable. Nutrient-uptake data for wheat obtained by Lewis and Marmoy (unpublished data), and by Knowles and Watkin,[4] mark the period of maximum increase in dry weight as mid-May to late June.

Irrigation is seldom applied to spring wheat, but the little evidence available points to the period—end-May to mid-June—as the irrigation period. A single water-application of 10–20 mm. should be sufficient.

Oats.—Numerous experiments have been made on the watering of oats, whose water-requirement is particularly high. Generally speaking, however, water-applications have been too heavy to be economic. Phenological data are important for determining the appropriate time to water oats. According to Brouwer[5] the oat crop is determined mainly by two comparatively short-growth phases: the first, 3–4 weeks after emergence, when the oat on soils with high water-capacity meets with temperatures which should be lower than normal if the yield is to be above the average. On soils with low water-capacity the oat responds to low temperature if rainfall is sufficient. The second period is that of shooting, at which the oat requires at least average rainfall. The first period is thought to be the more important; if weather factors then are not optimal the yield will be below expectation, but even with favourable weather, good plantings can reach full development only if water-supply is adequate at shooting. Roberts[6] came to practically the same conclusion from 24 years' work on oats at the College Farm, Aber, in North Wales. Honecker[7] found a somewhat later date for south Germany, namely, tillering date, as determinative. Berry[8] gives data for oats grown at Kilmarnock, Scotland, and shows a peak of N- and K-uptake at 28 days, but a prolonged uptake of P until crop maturity.

According to Liebscher,[9] uptake of nutrients by the oat plant, particularly of N and K, is relatively greatest in the first few weeks after emergence. In order to extend its root-system the oat requires at this time a cool soil and adequate moisture. Since Brouwer's[10] measurements of soil temperature are lower after artificial watering, both conditions are fulfilled by applying water in the first few weeks after emergence (about 15–25 days). Watering in the second period, the date of shooting, may be useful, but great care is necessary to prevent lodging. In experiments by Brouwer[11] in 1931 and 1932, watering was most effective if applied 14 days after the emergence of the oats; it was also effective when applied at the date of shooting. The efficiency of water varied very widely according to season and soil, 1 mm. rain producing an increase of anything from 20 to 90 kg. grain per hectare. For practical

[1] 1 dz. per ha. = 0·79 cwt. per acre.
[2] 1 mm. = roughly 1/25 inch.
[3] 1 kg. per ha. = 0·89 lb. per acre.
[4] *J. Agric. Sci.*, 1931, **21**, 612–37.
[5] *Landw. Jahrb.*, 1926, **63**, 1–81.
[6] *J. Agric. Sci.*, 1928, **18**, 297–316.
[7] *Archiv f. Pflanzenbau*, 1931–2, **8**, 185–95.
[8] *J. Agric. Sci.*, 1920, **10**, 359–414.
[9] *J. f. Landw.*, 1887, **35**, 335–518.
[10] *Landw. Jahrb.*, 1930, **72**, 375–457.
[11] *R.K.T.L.*, Schrift No. 49, 1936.

conditions, a water-application of about 15 mm. soon after emergence of the oats is advocated.

Barley.—The climatic requirements of spring barley do not differ essentially from those of oats. Low temperatures in the first few weeks after emergence are favourable to growth; rainfall during shooting is, however, less important than to oats. According to Liebscher (loc. cit.) nutrient-uptake is maximum in the first 3 weeks after emergence. Similar nutrient-uptake data have been obtained by Lewis and Marmoy (unpublished data). A few experimental results with barley are reported by Brouwer[1] and indicate a watering-date of 10 to 30 days after emergence. An increase of 2·25 dz. grain per hectare resulted from an application of 15 mm. water 10 days after emergence, but the crop lodged; i.e. 1 mm. water produced an increase of 15 kg. grain per ha. The susceptibility to lodging of the barley variety under test is an important factor in irrigation at any date; unless the barley variety is resistant to lodging, it should not be watered at shooting.

Mangolds.—Watering experiments on mangolds have been carried out by Gerlach[2,3] and Richter[4] but were a failure. The cause of failure is evident from data obtained by Brouwer on a diluvial loam soil over a period of 18 years, which show that rainfall-level in the first 6 weeks is immaterial. Yield-increases on watering at increasing rates are only apparent after about 100 days. There is a definite relationship between yield and temperature; to thrive freely the mangold requires warm weather, particularly in the first 8–9 weeks after emergence. According to Liebscher (loc. cit.) nutrient-uptake proceeds almost uniformly with the production of organic matter. Since the main development of the plant begins only about the middle of July, the relation between nutrient-uptake and water-requirement is explained. Gerlach[2,3] and Richter[4] watered mangolds very early, so that the fall in soil temperature damaged the young plants. Moreover, the amount of water applied—200 mm. up to the end of July—was high, notwithstanding that mangolds need a rainy district and soils with good water-retaining power. Brouwer based his irrigation-treatments on phenological readings and obtained an increase in yield of 89 dz. roots per hectare from an application of 80 mm. water applied between July 12 and August 27, i.e. 1 mm. rain produced an increase of 112 kg. per ha. The same amount of water was useless when put on in June and July, although the season was dry (1932). Yield data are given in Appendix I.

Sugar-beet.—This crop has much the same weather-requirement as mangolds. Briem, Hanamann, Hecker, Holdefleiss, Grohmann, Grouven and Scheinert, cited by Brouwer, are in agreement that sugar-beet responds to plentiful rainfall in July. Nutrient-uptake proceeds as in mangolds. Gerlach and Gropp[5] report watering-experiments on sugar-beet on loam-sandy soil. In 1913 there was only a small increase in

[1] *R.K.T.L.*, Schrift No. 49, 1936.
[2] *Mitt. d. K.-W.-Inst. f. Landw. in Bromberg*, 1908, **1**, 321–53.
[3] *Mitt. D.L.G.*, 1925, **40**, 363–6.
[4] *Mitt. d. K.-W.-Inst. f. Landw. in Bromberg*, 1914, **6**, 143 *et seq.*
[5] *Mitt. D.L.G.*, 1917, **32**, 352–8.

yield; in 1914 an increase of 85 dz. per ha. was obtained by adding 115 mm. water, and in 1915 an increase of 49 dz. from an application of 100 mm. water. Brouwer watered sugar-beet in the same way as mangolds and obtained an increase of 60 dz. beet per hectare from the late application, i.e. 1 mm. water increased the yield by 89 kg. beets per hectare.

Carrots.—Late application of water to carrots yielded an increase of 190 dz. per hectare from a total application of 60 mm. water, applied at the end of June and middle of July, i.e. 1 mm. rain produced an increase of 319 kg. carrots per hectare. Failure in irrigation experiments by Gerlach[1] is attributed to watering too early; the main growth of carrots is in July and August.

Potatoes.—Much work has been done on potatoes. Brouwer's[2] experiments on the variety Industry indicated that weather conditions are immaterial up to the time of flowering. In the first 3–4 weeks after flowering, low temperature favours growth; on light dry soils adequate rainfall is important. After the last-named period too much water is injurious. Nutrient-uptake by the potato plant conforms to this phenological relationship. Since sufficient nutrients are present initially in the tuber, root-development is the first activity. Depending on the rate of growth of the plant, nutrient-uptake ceases for at least 3–4 weeks, then proceeds gradually, reaching its maximum after 8–9 weeks, when tuber-formation begins. Lewis and Marmoy (unpublished data) find practically the same date for English conditions. According to Liebscher (loc. cit.) and Remy,[3] nutrient-uptake is maximum for early potatoes in June and for late potatoes in July, i.e. about blossom time. It appears, therefore, appropriate to begin watering when the flowers open.

Krüger[4] carried out experiments on different varieties in 1909–11 and obtained considerable, but uneconomic increases in yield for the variety Professor Maercker by applying 120–200 mm. water in the middle of May. In 1910, water applied in July and August, at a rate not exceeding 40 mm., gave profitable increases on the variety Silesia but decreases in yield when applied in May. In the very dry year 1911—only 97 mm. rain were recorded up to harvest—the efficiency of artificial rain was very different. The best results were obtained in the two extreme watering-periods, i.e. the longest from June 1 to August 29 and the shortest from July 4 to August 5, in which 280 mm. and 90 mm., respectively, were distributed. Krüger concluded from these three years' results that potatoes must be watered early. Brouwer thinks this erroneous.

Freckmann and Siegert[5] carried out a 3-year experiment from 1922–4 on eight potato varieties. Varietal differences were very marked, but in all cases substantial yield-increases were obtained from watering. Results obtained by Gerlach and Gunther[6] in 1925, using four varieties on light sandy soil, and by Deubel and Heitz[7] with two varieties on loam in 1927,

[1] *Mitt. d. K.-W.-Inst. f. Landw. in Bromberg*, 1908, **1**, 321–53.
[2] *Landw. Jahrb.*, 1926, **63**, 1–81.
[3] *Mitt. D.L.G.*, 1931, **46**, 188–91.
[4] *R.K.T.L.*, Schrift No. 49, 1936.
[5] *Mitt. D.L.G.*, 1925, **40**, 997–1002.
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[7] *R.K.T.L.*, Schrift No. 49, 1936.

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also showed yield increases. Although the results were not very consistent, they suggest that later watering and lower rates of application of water are preferable.

Brouwer carried out a series of experiments directed mainly to the optimum date of watering. In 1929 when watering was begun about 14 days after emergence, the yield was decreased by 11·5 dz. per ha. on applying a total of 70 mm. water to the variety Modrows Gisevius (8-fold replication). He then watered the same variety on the following plan:

Plot 1 Unwatered.
„ 2 Watered from May 15 every 5 days with 15 mm.
„ 3 „ „ June 1 „ 5 „ 15 „
„ 4 „ „ June 15 „ 5 „ 15 „
„ 5 „ during the flowering period twice with 15 mm.
„ 6 „ „ „ „ once „ 15 „

The plant came up on May 25 and began to flower on July 2. Yields were as follows:

Plot	*Artificial rain* mm.	*Yields*			*Increase in yield, as compared with unwatered of*		*1 mm. artificial rain increased yields per ha. by*	
		Tubers		*Starch*	*Tubers*	*Starch*	*Tubers*	*Starch*
		dz. per ha.	±	*dz. per ha.*	*dz. per ha.*	*dz. per ha.*	*kg.*	*kg.*
1	0	237	7	38	..	..	..	..
2	120	302	17	48	65	10	54	9
3	90	307	16	50	70	12	78	14
4	75	366	9	58	127	20	170	27
5	30	353	11	54	116	17	385	55
6	15	380	9	43	41	5	276	34

The good effect of watering, particularly at the time of flowering, is evident. One or two water-applications at this phase of growth were very well repaid.

To complete the work, Brouwer did a series of experiments on a very light, fine sandy soil to determine the best date of watering within the flowering-period. The yields recorded again show the benefit of watering just after flowering begins.

The effect of watering at different dates just before flowering and during flowering was later tested on 14 different varieties. Results are tabulated in full by Brouwer (loc. cit.), and it is clear that the efficiency of artificial rain is considerably greater when the water is applied just after flowering starts than at the several other dates tested. Generally speaking, 20 mm., or at most 40 mm., of water was the most economic rate. On light sandy soils in the dry year of 1932, for which yields are recorded for two varieties, it is evident that a single 20 mm. application of water had a striking effect in increasing yields: 1 mm. artificial rain increased the yields of Cymbals Professor Wohltmann by 487·50 kg. and of Kaiserkrone by 362·5 kg. per hectare. With the exception of the varieties Rosafolia, Jubel, and Parnassia, all varieties grown in 1932 gave satisfactory increases in yield as a result of watering. The 1932 results

further indicated that the increase in yield was mainly an increase in big tubers, the number of small tubers not being appreciably altered.

Grassland

There are few observations on the effects of weather on grassland yields. Bürger[1] considers that winter rainfall determines the yield of hay. Remy[2] has shown that storage of reserves in roots of meadow and pasture plants (*Festuca pratensis* and *Lolium perenne*) takes place in autumn and early winter, and Bürger[1] concludes that in dry autumns sprinkling or irrigating would be more beneficial in autumn than at any other time. According to Höhne[3] and Brouwer, the winter months are not important. Höhne recorded data on a meadow on heavy loam soil and found that high temperatures towards mid-April had a good effect whilst weather factors had little effect at other dates. Work by Blackman[4] at Jealott's Hill confirmed this temperature-effect and showed that below 42° F. temperature is the factor controlling the growth of pasture in spring. Höhne found that weather for the fortnight following the first cut is without influence on the second cut. Brouwer's[5] experiments largely confirm this, but show that the effect of weather on hay-yields varies according to manuring, soil type, and ground-water level. The composition of the sward is also a factor. Mitscherlich,[6] Freckmann,[7,8,9] Schwartz,[10] and others have shown that the amount of water required for the production of 1 gm. dry matter varies with plant species; the amount of water needed by common grasses averages about 500 gm. Krüger[11] investigated the effect of watering a meadow on sandy soil in 1909, but neither he nor his successor Richter[11] was able to approach profitability in experiments in the years 1910–14. In the wet year 1912 the yields decreased, whilst in the other years the water-applications were so high that the costs far surpassed the returns. Freckmann,[12,7] carried out watering experiments on meadows and pastures on a loam-sandy soil in 1926 and 1927; a water-application of 105 mm. on meadows in 1926 was the only economic one. It is calculated that 1 mm. artificial rain in these experiments gave the following yields of hay per hectare:

Year	*Quantity of water mm.*	*On meadow kg.*	*On permanent pasture kg.*
1926	105	49·5	20·9
	320	26·3	8·7
1927	90	23·3	22·2
	370	13·8	13·8

[1] *Deut. Landw. Presse*, 1930, **57**, 63–4.
[2] *Landw. Jahrb.*, 1923, **58**, 655–90.
[3] *Archiv f. Pflanzenbau*, 1932, **8**, 345–70.
[4] *J. Agric. Sci.*, 1936, **26**, 620–47.
[5] *Archiv f. Pflanzenbau*, 1926–7, **3**, 330.
[6] *Der Kulturtechniker*, 1926, **29**, 46–53.
[7] *Meliorationswesen: Handbuch der Bodenlehre*, 1931, vol. 9.
[8] *Landw. Jahrb.*, 1926, **64**, Ergänz.-Bd. I, 34–62.
[9] Ibid., 1928, **68**, Ergänz.-Bd. i, 35–51.
[10] *Archiv f. Pflanzenbau*, 1932, **8**, 276–334.
[11] *R.K.T.L.*, Schrift No. 49, 1936.
[12] *Landw. Jahrb.*, 1927, **66**, Ergänz.-Bd. I, 191–214.

Brouwer examined the influence of soil moisture, temperature, growth-stage of the plant, and herbage-composition on the effectiveness of irrigation. Since satisfactory phenological data were lacking, these were obtained for common grass species. Experiments on loam-sandy soil with grasses in pure stand showed that species differ in water-requirement. *Agrostis alba*, *Avena flavescens*, *Festuca rubra*, *Phalaris arundinacea*, and *Poa serotina* in the first cut responded to watering if the water was applied in the last three weeks before mowing; the same was true of the following grasses provided that the average temperature was at least 18° C.: *Dactylis glomerata*, *Festuca pratensis*, *Lolium perenne*, *Phleum pratense*, and *Poa pratensis*. There was frequent damage if watering was done at lower temperature. Watering did not increase the yield of *Avena elatior*, *Bromus inermis*, and *Lolium italicum*.

The yield of the second cut was regularly increased in all grasses except *Lolium italicum*. The most suitable date for watering *Avena elatior* and *Poa serotina* is about 10 days after mowing the hay. For *Agrostis alba*, *Avena flavescens*, *Festuca pratensis*, *Festuca rubra*, *Lolium perenne*, *Phleum pratense*, and *Phalaris arundinacea* the date is about 20 days after mowing the hay; for *Bromus inermis*, *Dactylis glomerata*, and *Poa pratensis* about 25–30 days after mowing.

The effect of watering on growth-activity of the grasses, especially in the second cut, is not so uniformly good as might be judged from the successful results of sewage-irrigation and from the high water-requirements of grasses. The increase in yield must be relatively great if the watering is to be economic. An examination of the earlier grassland-irrigation experiments shows that the minimum increase of yield for profitability was seldom reached. Yet the trend is to water grassland rather than arable.

Brouwer (loc. cit.) worked with a meadow having a sward consisting mainly of *Festuca pratensis* and *Phleum pratense* with *Phalaris arundinacea* and *Poa pratensis*. He also irrigated a meadow in which the composition of the first cut was *Dactylis glomerata* 50–70 per cent. with *Lolium perenne* and *P. pratensis*. Water was applied to the first cut with the results shown in Appendix II. Increases up to 22 dz. per ha. of hay were obtained by watering at the 20 mm. level during the last three weeks before mowing, provided that soil temperature was adequate; i.e. 1 mm. rain increased the yield by 112 kg. hay per hectare. Under such conditions watering is very profitable. Brouwer has carried out many watering experiments on second cut but has not been able to obtain economic increases in yield. Watering was more effective when done late than when done early, and low levels of water were as effective as higher levels.

Summarizing the position in an address to the Third International Grassland Congress in 1934, Brouwer[1] stated that carefully regulated application of 10 mm. of water to meadows during the three weeks before mowing had given an average increase over three years of 10 dz. hay per hectare (nearly 8 cwt. per acre). The cost of watering was 12 RM. per 10 mm. per ha.

Pastures have been watered experimentally to a greater extent than

[1] *Report of the Third International Grassland Congress*, 1934, pp. 89–95.

meadows. Much success had been reported, but the data are not generally applicable because of the difficulty of evaluating pasture productivity.[1,2,3,4] Tiemann and Müller[2] report an increase in crude protein from 17·6 to 24 per cent. and economic increases in terms of milk-production from heavy watering.

In his pasture experiments, Brouwer assumed that watering would be ineffective in the first grazing-period and in the early part of the second. The results obtained on watering a sward of *Poa pratensis*, *Festuca rubra*, and *Dactylis glomerata* during the second, third, and fourth grazing-periods are tabulated in Appendix III. The data show the best results from water applied after about 4 weeks' grazing in the second period. Applications of 20–30 mm. are considered economic. The third grazing-period was dry and it was easy to obtain good increases from watering at all rates chosen. Early watering stimulated white clover, whilst late watering promoted the growth of grasses. In the fourth grazing-period the date of watering is specially important: the growth-energy of the grasses has fallen off, and leafy growth (clover and weeds) occupies a large part of the area. Supplemental rain is very profitable if given only after about 14 days' growth. Brouwer considers that water-application in any of the last three grazing-periods should not exceed 15 mm. to a maximum of 30 mm. in one or two applications, respectively.

Brouwer did not find in his experiments that nitrogen was better utilized by grasses on irrigated pastures or meadows. He points out that results at different intensities of manuring vary in such a way that the effect of water may be masked. Heavy nitrogenous manuring promotes the growth of grasses like *Dactylis glomerata* and *Poa pratensis*, which in any case utilize nitrogen very efficiently. Management of pastures is also an important factor. The complexity of the subject is shown in a further paper by Freckmann and Brouwer.[5] Borchardt[6] also was unable to obtain any better utilization of nitrogen in his irrigation experiments. Schonnopp,[7] on the other hand, considers that watering ensures the better utilization of any fertilizer application. Greenhill[8] carried out experiments on a pasture in supplementing natural rainfall by watering, and showed that from early in the season onwards grass-production was limited by the supply of soil moisture; the productivity of the pasture was markedly increased by raising the levels of nitrogen and water-supply, and the productivity-curve was flattened out very considerably. Strong indications of an interdependence of water and of nitrogen-supply in their effect on productivity were observed, and also the effect of water-supply in increasing the effectiveness of superphosphate applied in mid-season to nitrogen-treated pastures. It was realized during the experiments that more economic results would have been obtained if water-applications had been based on soil-moisture deter-

[1] *Mitt. D.L.G.*, 1930, **45**, 352–4.
[2] *R.K.T.L.*, Schrift No. 38, 1933.
[3] *Landw. Jahrb.*, 1937, **85**, 245–62.
[4] Jealott's Hill unpublished data.
[5] *Landw. Jahrb.*, 1934, **80**, 39–72.
[6] *Diss., Landw. Hochschule, Berlin*, 1931.
[7] *R.K.T.L.*, Schrift No. 38, 1933, 135–54.
[8] *Trans. Int. Soc. Soil Sci.*, 1935, **1**, 256–8.

minations rather than on rainfall data. The interdependence of water and nitrogen supply is clearly demonstrated by Rackmann[1] in pot experiments with 10 common pasture grasses grown at Limburgerhof, and confirmed in the field by Ahlgren[2] at Madison, Wisconsin, in experiments on a *Poa pratensis* sward.

Milton[3] studied the effect of irrigation on the growth and relative palatability of certain grasses and clovers grown in plots of pure species and found that both were increased:

Relative Growth and Amount Eaten of each Species (Markings on a scale of 0–10 averaged for the grazings)

	Relative growth		*Relative amount eaten*	
	Irrigated	*Non-irrigated*	*Irrigated*	*Non-irrigated*
Perennial rye (S 23) . .	8·2	6·4	7·9	7·5
Cocksfoot (S 26) . .	7·8	7·2	6·8	6·4
Timothy (S 48) . . .	7·4	4·8	8·7	6·0
Broad red clover . . .	5·5	3·7	9·2	7·6
Wild white clover . .	6·6	5·4	8·9	8·0

Pasture-irrigation is practised on dry farms in Tillamook County, Oregon, where there is an annual rainfall of 75 in., but little in the summer. In 1937, according to Price,[4] there were 35 revolving-sprinkler installations costing $1,000 each. They are claimed by the farmer to pay for themselves in 2 years. In a trial installation, irrigation of 12 acres of pastures increased the butter-fat of a herd of 44 cows by 1,378 lb. or $401. Irrigation of 20 acres increased the butter-fat value by $613. The cost of electric power was $5 per acre per season.

Horticulture

All leafy vegetables have a high water-requirement and field watering has been employed extensively for them. Often soil can only be used for vegetable growing with the aid of watering apparatus. Experiments on the proper time to water are lacking and the problem is complicated by the absence of phenological records. Little more is known than that rainy years generally synchronize with good vegetable years.

Watering experiments on cabbages on light sandy soil by Krüger[5] in 1910 and 1912, and by Richter[5] in 1913, gave negative results and showed only that on poor soils cabbage cultivation is not possible even with the aid of water. Other experiments on heavy soils showed, however, that watering cabbage can be extremely profitable. Krüger was able to obtain good returns, at least with sparing application of supplemental rain. Hagenbucher mentions considerable increases in cabbage crops, but gives no experimental data.

[1] *Bodenk. u. Pflanzenernähr.*, 1938, **9/10**, 457–506.
[2] *J. Amer. Soc. Agron.*, 1936, **28**, 515–33; 1938, **30**, 688–91.
[3] *Empire J. Expt. Agric.*, 1938, **6**, 150–6.
[4] *Agric. Engineering*, 1938, **19**, 161–2; *C.R.E.A.*, News Letter No. 17, 1938, 38–40.
[5] *R.K.T.L.*, Schrift No. 40, 1936.

Brouwer (loc. cit.) watered cabbage species in 1932 and obtained yield-increases up to 360 dz. per hectare for the variety Mammoth Red by applying 60 mm. artificial rain. Late watering—about 70 days after planting—gave considerably better results than earlier watering, and watering with 60 mm. was extremely profitable. July watering is consistent with data of Becker-Dillingen[1] and Remy[2] for course of nutrient-uptake. Irrigation was tested on French beans in the humid sections of Oregon in 1923–35 (Price[3]). The annual rainfall is 40 in. with little summer rain. Control plots yielded ½ to 1¼ tons per acre; the irrigated crop went up to 5–6 tons per acre, giving a profit from watering of $120–30 per acre. It is reported common now to get 10–14 tons of French beans per acre by watering and improved fertility. The yield of table beet has been increased by 150 per cent. and that of carrots by 300 per cent. Sprinkling is preferred to furrow-irrigation. In England, Secrett[4] considers 8,000 ft. of spray lines an economic unit, and applies water in preparing land for a seed-bed and to growing vegetable crops. Rochfords of Taplow also irrigate market-garden crops[5] by the Kinnell system.

Summary

A fair amount of experimental work has been carried out, mainly in Germany, to find how far yield can be increased by watering and the right date to water. Though the experimental technique is not the most up to date, the results indicate that water applied by sprinkling increases the yield of farm crops and of grass.

Phenological data and nutrient-uptake data generally point to one or more peaks of growth-rate constituting phases in the life of the plant. These phases are considered to be 'critical' phases, and the critical date or dates appear to be optimum dates for watering. Water applied at a resting stage, for example, is valueless, and compensation for deficient natural rainfall at fixed intervals is not the principle underlying efficient watering. Critical dates are difficult to determine; nutrient-uptake depends on the nature of the crop and also on climate and soil; in some plants nutrient-uptake may be prolonged over a period. The following dates are, however, suggested by the experiments:

Autumn wheat: before shooting.
Spring oats: 2–3 weeks after brairding and at shooting.
Potatoes: directly after the beginning of flowering, and 14–15 days later.
Sugar-beet: 13–14 weeks after emergence.
Grassland: at dates depending on hay-cut or grazing-period.

Ranges of increase in crop-yield obtained experimentally from applying about 15–20 mm. supplemental water at the critical date are shown below; increases obtainable by manuring are added for purposes of comparison. Reduced to yields per 1 mm. water and per ½ inch water,

[1] *Handbuch des Hackfruchtbaues und der Handelspflanzen*, 1928, p. 489.
[2] *Mitt. D.L.G.*, 1931, **46**, 188–91.
[3] *Agric. Engineering*, 1938, **19**, 161–2; *C.R.E.A.* News Letter No. 17, June, 1938, 38–40.
[4] *J. Roy. Hort. Soc.*, 1936, **60**, 294–303; *J. Roy. Soc. Arts*, 1935, **84**, 126–55.
[5] *Farmer and Stockbreeder*, 1938, **52**, 2141, 2163.

and on the assumption that yields are progressively increased by 1 mm. water up to the 20 mm. level, the data are as follows:

	Yield per ha. per mm. water	*Yield per acre per ½ inch water*	*Yield per acre per 1 cwt. sulph. ammonia*
Autumn wheat	70 kg. grain	16 cwt.	2·2 cwt.
Spring oats	50–70 kg. grain	12–17 cwt.	3·3 cwt.
Barley	10–20 kg. grain	2½–5 cwt.	3·2 cwt.
Sugar-beet	55–90 kg.	14–22 cwt.	10–15 cwt.
Potatoes	170–400 kg.	2–5 tons	1 ton
Hay	100 kg.	1¼ tons	8 cwt.

The figure for barley is low because of lodging; that for potatoes varies largely with the variety. The grass sward tends to become clovery if watering is not timed carefully; its nutritive value and palatability may be increased by watering.

It is difficult to arrive at a figure for the cost of watering because conditions vary from farm to farm. Capital costs vary widely. Water may be cheap for instance where the farm borders a stream, or where the water-table is high, as in alluvial gravels typical of market-garden soils. At the other extreme, mains water may have to be used and may cost up to 1*s.* 9*d.* per 1,000 gallons. At this extreme price, application of the equivalent of 1 inch of rain in 8 hours, or 3,000 gallons of water per hour per acre, would cost 42*s.* per acre for water alone. The cost of equipment and water is not prohibitive to successful market-gardeners. Whether increase in yield of field crops of the order given above is obtainable under ordinary farming conditions appears to be a question for examination by the individual farmer.

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APPENDIX I

EFFECT OF WATERING ON YIELDS OF MANGOLDS AND SUGAR-BEET

Treatments

Plot	*Quantities of water in mm. on*					
	14. vi. 1932	*27. vi. 1932*	*12. vii. 1932*	*13. viii. 1932*	*20. viii. 1932*	*27. viii. 1932*
1. Unwatered	..	..	..	..	..	..
2. Added water	15	15	20	20	..	..
3. „ „	..	15	20	20	20	..
4. „ „	..	..	20	20	20	20

Since the beet had emerged on April 27, 1932, water was applied 48, 61, 76, 108, 115, and 122 days after emergence.

APPENDIX I—*continued.*

Mangolds

Plot	Yield		Increase (+) or decrease (−) in yield over unwatered		Increase in yield per 1 mm. artificial rain kg. per ha.
	Roots dz. per ha.	Tops dz. per ha.	Roots dz. per ha.	Tops dz. per ha.	
1	1,301	203	..	..	..
2	1,295	161	−6	−42	..
3	1,357	180	+56	−23	75
4	1,390	185	+89	−18	112

Sugar-beet

Plot	Yield		Increase (+) or decrease (−) in yield over unwatered		Increase in roots per 1 mm. artificial rain kg. per ha.
	Roots dz. per ha.	Tops dz. per ha.	Roots dz. per ha.	Tops dz. per ha.	
1	624	392	0	0	..
2	631	329	+7	−63	10
3	666	380	+42	−12	56
4	685	463	+61	+71	89

Data reported by Brouwer, *R.K.T.L.*, Schrift No. 49, pp. 33, 34.

APPENDIX II

EFFECT OF WATERING ON HAY-YIELD OF MEADOWS

Sward: *Festuca pratensis—Phleum pratense*

Year	Water mm.	No. of waterings	No. of days before mowing on which water was applied	Increase over unwatered hay dz. per ha.	1 mm. water increased hay-yield by kg. ha.	Av. temperature and rainfall in days before the first cut				
						1–10	11–20	21–30	31–40	41–50
1929	58	2	17 and 20	+ 7·7	13·8	19·4	13·1	17·5	13·2	13·1° C.
						2·4	42·0	7·2	28·4	21·7 mm.
1930	107	5	6, 12, 25, 26, and 41	+13·0	12·1	17·2	16·2	12·2	12·4	13·4° C.
						0·0	15·2	30·8	30·3	7·3 mm.
1931	20	1	15	+19·5	97·8	14·9	20·3	17·9	14·2	9·1° C.
						37·6	56·2	27·4	6·8	10·9 mm.
1932	20	1	21	+22·2	111·8	13·7	15·7	18·5	10·6	11·0° C.
						24·4	43·6	0·3	20·1	14·5 mm.

APPENDIX II—*continued.*

Sward: *Dactylis glomerata*

Year	Water mm.	No. of waterings	No. of days before mowing on which water was applied	Incr. or dec. over unwatered hay dz. ha.	1 mm. water increased hay-yield by kg. ha.	Av. temperature in days before the first cut °C. 1–10	11–20	21–30	31–40
1930	10	1	26	− 0·4	..	16·2	12·2	12·4	13·4
	47	4	4, 14, 21, and 26	+ 2·3	4·9	*16·2*	*12·2*	*12·4*	13·4
	110	7	4, 9, 10, 14, 15·1, 21, and 26	+12·2	11·1	*16·2*	*12·2*	*12·4*	13·4
1931	10	1	3	+10·6	105·5	*20·2*	17·9	15·2	11·7
	40	2	3 and 5	+14·8	36·8	*20·2*	17·9	15·2	11·7
1932	10	1	22	+ 8·5	84·7	14·4	*19·0*	13·0	11·6
	10	1	18	+ 9·8	98·2	14·4	*19·0*	13·0	11·6
	10	1	14	+ 7·2	72·0	14·4	*19·0*	13·0	11·6

(Figures in italics indicate that watering was done in this 10-day interval)

Data reported by Brouwer, *R.K.T.L.*, Schrift No. 49, pp. 51, 52.

APPENDIX III

EFFECT OF WATERING ON HAY-YIELD OF PASTURES

2nd Grazing-period

Artificial rain mm.	No. of waterings	Days after the 1st grazing-period on which water was applied	Area I: Increase in hay over unwatered dz. per ha.	Area I: 1 mm. increased the hay-yield by kg.	Area II: Increase in hay over unwatered dz. per ha.	Area II: 1 mm. increased the hay-yield by kg. per ha.	Rainfall and temperature in the 10-day period after the 1st grazing-period: 1 to 10	11 to 20	21 to 30	31 to 40	41 to 50
							Rainfall, mm.				
40	3	3, 20, and 27	+ 5·5	13·6	+ 9·3	23·3	62·4	5·6	17·0	3·9	4·2
30	2	27 and 35	+ 7·2	23·8	+11·3	37·8	Temperature, °C.				
80	4	35, 39, 42, and 47	+10·5	13·2	+11·5	14·4	15·7	13·7	16·9	17·7	21·5

3rd Grazing-period

Water applied mm.	No. of waterings	Days after 2nd grazing-period on which water was applied	Area I: Increase in hay over unwatered dz. per ha.	Area I: 1 mm. increased the hay-yield by kg. per ha.	Area II: Increase in hay-yield over unwatered dz. ha.	Area II: 1 mm. increased the hay-yield by kg. per ha.
10	1	30	+ 8·0	79·5	+6·0	59·7
20	1	7	+12·8	64·8	+6·0	29·8
40	2	4 and 12	+13·1	32·8	+5·6	13·9

4th Grazing-period

Water applied mm.	No. of waterings	Days after 3rd grazing-period on which water was applied	Increase in hay-yield over unwatered dz. ha.	1 mm. increased the hay-yield by kg. per ha.
20	1	6	+ 9·4	46·9
20	1	17	+15·1	75·4
60	3	6, 10, and 17	+15·7	26·2

Data reported by Brouwer, *R.K.T.L.*, Schrift No. 49, pp. 57, 58.

THE SOILS OF CUMBRIA: A PRELIMINARY STUDY

T. H. BAINBRIDGE

WITH 6 MAPS

Introduction

ON the lowlands of Cumbria, where the effects of glaciation are so often seen, the soils are usually of the transported type, although in many places it is still possible to recognize the sources from which the constituents were derived.

The most extensive of the transported soils are those derived from boulder clay, the general appearance of which is well known because of its frequent outcrops. The term 'clay' must, however, be interpreted with caution, because it suggests a homogeneity that is usually lacking. Departure from a true clay-type of soil results from the interstratification by beds of sand and gravel, and in some parts of the Solway Plain the soil becomes a stony clay sufficiently sandy, when dry, to crumble to sand between the fingers. Minor bands of fine sand sometimes cause abrupt changes in the soil, from heavy clay to loamy sand, so local that they cannot be shown on small-scale maps. These are in contrast to areas where stiff unweathered clay is encountered at a depth of a few inches. Usually the boulder clay is reddish, although where it rests on, or is largely derived from, coal measures, as in the northern part of the coastal plain, it is yellowish, and is predominantly yellowish-brown where derived from Skiddaw Slates.

The great variation within the boulder clay, coupled with the diversified topography, produces a wide range of drainage conditions, and permeability varies from very low to very high values. Small tracts of marsh or waterlogged pastures can frequently be seen between the drumlins.

The boulder clay occurs in broad sheets, as disconnected patches, and in the form of drumlins; and on the whole would be most nearly described as a 'stony loam'.

The laminated clays frequently show well-defined colour banding and a strong tendency to break or peel off along the bedding planes. Occasionally they are interbedded with loams and sands. An important feature of these drift deposits is their comparatively or wholly stoneless nature. The influence on the economy of the region is marked, because in addition to providing a useful soil for arable farming, it has also been the source of clay for brick-making.

Like the boulder clays, the glacial sands and gravels are extremely variable accumulations, whose accepted names are sometimes inapposite. They vary from coarse to fine and in the amount of gravel they contain. In places it is possible to find a lateral displacement of gravel by sand and ultimately by laminated clay and loam. As a whole, soils derived from this type of drift tend to be loamy, because bands of clay are often present in the sand and it is frequently overlying boulder clay. One of the greatest continuous accumulations of sand and gravel is the Brampton

Kame-belt, which covers an area seven miles long and two miles wide. Along the Tyne Gap, too, there is an almost continuous chain of sand and gravel, and there are also noticeable deposits in the Wigton region.

Alluvial soils can be divided into two groups, the marine alluvium or warp and the fluviatile alluvium. The marine warp lands are most extensive on the Solway Plain and Furness Lowlands and form most of the low ground between the coast and the areas covered by inland drift. In places the soil is a grey sandy clay; near the boulder clay it becomes a blue-grey and starchy clay, but generally it is a pale yellow and brown sandy loam. Large areas of the warp lands are under cultivation and make fertile regions, which, when well drained, are covered with a close-growing, weedless, fine-bladed grass, much in demand as turf for lawns and tennis courts (Solway turf). The most important use is for grazing, the land being frequently held under common rights. Where drainage is neglected the soil becomes rank, waterlogged, and unproductive.

Fluviatile alluvial deposits are well developed over many parts of Cumbria, but are not as extensive as the marine warps. They occur particularly in the lower and middle Eden Valley, the Esk, the Duddon, and Furness rivers, e.g. near the Gilpin and Kent estuaries. Other detached spreads are usually between lakes or on the sites of former lakes, but unless they have been drained their wetness prevents adequate use being made of the ground. The alluvial flats between Derwentwater–Bassenthwaite and Buttermere–Crummock are the best-known examples.

The alluvium is extremely variable, being in some places a sandy clay and in others peaty or clayey; frequently it becomes coarse and contains gravel, but is then more free-working, even if somewhat hungry and sharp. On the whole the alluvial soils are deep and well-mixed, having a good supply of humus and not over-consolidated. They are perhaps best described as loams.

Extensive areas on the Solway Plain and Furness Lowlands are covered with peat. The larger deposits are situated upon the warp or boulder clay, whilst the smaller 'mosses' occupy either river valleys or hollows, often between drumlins. It is noteworthy that soils of reclaimed mossland areas are amongst the most uniform, being distinguished, as would be expected, by a high proportion of organic matter. These soils contain a good reserve of nitrogen, but are short of potash and phosphate. Hill-peat forms a covering, and frequently masks the rocks, on many of the upland slopes. It is very extensive on the Alston Block, where its boundaries and thickness are very irregular; it also occupies much of the Howgill Fells and occurs on the Helvellyn ridge.

Along the coast of Cumbria there are three large areas of blown sand. The most northerly extends from Silloth to Beckfoot, covering a raised beach, and occasionally it becomes thick enough to form dunes and sand hills. Farther south, extensive deposits occur round the Ravenglass estuary, and round the mouth of the Duddon and on Walney Island. Fig. 1 is an attempt to show the general soil divisions of Cumbria and has been compiled after a careful study of the large-scale maps.

Solway Plain

By far the larger part of the Solway Plain is covered with boulder clay (Fig. 2), the matrix of which is mainly of local origin, and the colour reddish where it overlies the New Red Sandstone. Such soils are generally medium-texture loams. In other parts where the boulder clay rests on Carboniferous rocks there occur soils varying from medium-textured loams to stiff clays.

South-west of Carlisle, through Wigton and on to Maryport, the soil is also loamy, varying from a red sandy loam to a red clay loam, 9–12 in. deep. It provides a good ploughable soil, apart, of course, from the unwanted boulders.

Sandy soils occur east of Carlisle, where there is a district covered with a light sandy soil which, like the majority of this type, is somewhat hungry and quickly reflects the action of drought.

Extending from Brampton southward some seven miles, and having an average breadth of two miles, there is one of the most extensive tracts of sandy soil in the whole of Cumbria. This area, which extends from the Solway Plain into Edenside, is due to the existence of the Brampton Kame-belt (which accounts also for the undulating topography). Usually there are 2 ft. or more of sandy soil overlying the red sandstone, and this fact, combined with the ease of working and the diversified topography, ensures a soil well suited for most agricultural purposes, indeed, one of the best in the whole of NW. England. The valleys are better watered than the hills, the bold relief of some of the kames and oses, and the light gravelly nature of others, rendering some areas of soil quick to respond to droughty conditions.

Other but less extensive areas of sandy soil occur to the west and south-west of Carlisle, the largest being on the sites of eskers or esker-deltas. A flatter stretch of glacial sand and gravel extends from the Eden, west of Rockcliffe, to the Esk, but this is liable to suffer in time of drought. The one remaining sandy-soil district is that immediately north of Aspatria. These sandy soils are merely 'islands' in the greater area of soils derived from the boulder-clay drift; they are usually early soils and are liable to suffer from drought.

The alluvial deposits in valleys like those of the Eden and Esk, along with the Caldew, Petteril, Irthing, Gelt, King Water, and Wampool, in general give rise to sandy loam. Where the alluvium is liable to flooding it is frequently used for grazing. Where free from periodic floods, as in the Wampool valley, or where reclaimed by dykes, as in the valleys of the Eden, Esk, and Lyne, it provides a useful soil for arable farming.

Along the coast from Allonby Bay to the international boundary at the mouth of the river Sark, the Solway Plain is fringed for varying distances by soils which are interesting because they have been derived from the marine warp; and although they are essentially alluvial, they do show variations in character. The deeply dissected marsh-land of the Solway estuary, which is subjected to periodic inundation, is covered in the main by a fine, brown, sandy loam. Similar grazing land occupies the first terrace of marine warp, which has its maximum development

west of Kirkbride, where it provides a brown soil usually a foot or more in depth and resting on yellow clay. The second terrace, which provides the greater part of the warp lands, is covered by a brown sandy loam resting on a subsoil formed of blue clay. The soils on these warp lands are usually fertile and cultivable if well-drained, but as the land is flat and low in elevation, it quickly becomes waterlogged and unproductive when draining is neglected; most of the settlements are on boulder clay or gravel outcrops.

Standing like islands in this part of the Solway Plain are expanses of peat, the largest being on the Cardurnock Peninsula and comprising Bowness and Glasson 'mosses'. Doubtless this and others such as Wedholme Flow, Drumburgh Moss, Common Moss, and, farther afield, Solway Moss and Scaleby Moss, were formerly of greater extent. Fringing the margins there is frequently a light, black soil (known locally as 'black top'), which contains a high percentage of humus and provides grazing land and, in places, arable land.

Trotter and Hollingworth [1] have made a detailed pedological study of the area between Carlisle and Brampton, and compiled a soil map of the Brampton area.

Edenside

There are three broad soil divisions in Edenside, but not one of them is completely homogeneous. The Carlisle to Lancaster section of the London, Midland, and Scottish Railway as far south as the river Eamont—or to take a natural feature the river Petteril—divides drift deposits which give rise to soils that are in the main clayey to the west and sandy to the east. The latter will be considered first.

Following the base of the Pennine escarpment is an extensive area of light sandy soil (Fig. 3), which occupies the southern portion of the Brampton Kame-belt mentioned previously. The features characteristic of the northern part apply also to this part; and ease of working and diversified topography, together with a fertile soil, make this area eminently suitable for arable farming. There are other quite conspicuous districts covered with sandy soil, but none so continuously extensive as those on the Kame-belt. Where the sandy soil is very light, it is subject to drought, and some of it is also acid.

To the west of the Petteril (the second division) the soil is essentially a dark loam, inclined to clay, and so provides a heavier type of soil than that farther to the east; it often contains many stones, and is generally associated with the Carboniferous rocks that are present in this region. There are considerable areas where the limestone is at or near the surface, and in these areas the land is well suited for grazing. South of the Eamont (the third division) the soil is an earthy clay. These heavier soils, with the relatively large number of boulders contained in the matrix, do not form such an easily worked soil as that found farther north, and are also in parts at a higher elevation.

In all parts of Edenside there are conspicuous spreads of alluvial soils, especially along the Eden. In that part of Edenside extending towards Ullswater and Haweswater, farmsteads and sometimes villages tend to

lie on or near alluvial patches, the most conspicuous being the villages of Crosby Ravensworth, and Great Asby. The higher portions of Great Asby Scar are singularly free from drift or peat, the rock forming a bare limestone 'pavement' for some distance.

The soil covering the Pennine escarpment and the foothills is chiefly derived from Carboniferous rocks, and boulder-clay material is mainly of local origin. In some places where the drift is thin, the surface-soil is derived from the underlying limestone or sandstone. On the higher areas, usually above 1,000 ft., peaty soils occupy extensive stretches where the slopes are less steep.

Coastal Plain

(*a*) *North.*—Over the northern section of the coastal plain, which may be considered as extending from the river Ellen to St. Bees Head, the soil is derived mainly from the boulder clay that covers much of the district (Fig. 4). As it overlies Carboniferous rocks, the heavy boulder-clay soil is usually dark; its depth varies from 6 to 12 in., and it covers a yellowish or bluish clayey subsoil. This subsoil is very compact and contains many boulders or 'set-fasts', as they are called. Besides being difficult to work, such soils are cold and late, with a high moisture-content, and are usually under grass, being too heavy and wet for very intensive cropping.

On the limestone outcrops, especially in the narrow north-and-south belt, west of Cockermouth, the lower land is covered with 6–9 in. of a fairly heavy loam resting on the limestone. This soil provides the best grass in the district, and rents are much higher than for farms on the clay soils.

The alluvial soils are well disposed on the valley floor of the Derwent and generally overlie a gravelly subsoil. Being less stiff than the clays, and containing fewer obstructions to the plough, these well-mixed soils provide the best arable areas in this part of the coastal plain. Farms with the largest proportions of cropped land are therefore situated between Workington and Cockermouth.

There are other patches of alluvial soils, of which the most continuous lie in the Ellen valley. This has not the broad floor of its southern neighbour the river Derwent, and the only considerable spread is that near Maryport.

Soils derived from sand and gravels are inconspicuous in this region, more particularly from the farming point of view.

Around the southern part of the coal-field on the uplands which rise conspicuously from the surrounding land, the sandstone has given rise to a soil which provides grass suitable for sheep.

(*b*) *South.*—The southern portion of the west-coast plain differs materially from the section north of St. Bees Head. Although mantled by the usual boulder-clay deposits, the matrix of the drift bears a strong relationship to the underlying red sandstone.[1] Generally speaking, over the larger part of this region the soil varies from a red sand to a red boulder clay.

[1] Aveline has said that the red sandstone is 'buried in its own waste'.

On the lower ground in the St. Bees district, inland from the headland itself, the soil consists of a red sandy loam, about 9 in. deep, overlying the St. Bees red sandstone. The relative lightness of the soil here accounts for the high proportion of arable land, and the farms on this loamy area command the highest rents in this part of the coastal plain. Around Egremont the red boulder clay is heavier, usually being superimposed upon what is termed 'roach' (iron ore and clay). In this area drainage needs attention.

Between Gosforth and the river Irt there is a fairly extensive area covered by sandy soil extending to the coast. Despite the adequate rainfall (more than 40 in.), some of the very sandy soils are liable to drought. Around the Ravenglass estuary lie some of the most extensive areas of blown sand in Cumbria, which are unsuitable for farming.

Southwards from Corney the soil consists of red clay mixed with sand and gravel (Fig. 5). This fertile soil owes much to its proximity to the Eskdale granite, which outcrops east of the red sandstone.

The greatest areas of alluvial soils are situated around the Duddon. Peat accompanies the alluvium in places, e.g. near the head of the estuary. Other alluvial soils occur in the numerous river-valleys, especially those of the Esk and Ehen. Whitehaven stands on the northern end of an alluvial tract which stretches through the gap to St. Bees and has peaty areas within it. Peaty soil also occurs near the coast south of St. Bees.

The soils of this southern portion of the coastal plain with their lighter, sandy, and more fertile nature afford a contrast to the heavy clay soils north of St. Bees Head.

Furness Lowlands and Kent Estuarine Lowlands

The soils of the Furness district are in the main derived from the boulder clay (or 'pinel', as it is called locally) which completely masks the underlying rocks (Fig. 6). This surface-covering consists of a stiff clay containing boulders which gives rise in the west to what are best described as heavy or wet clay lands. In the main, the soil farther east around the estuarine lowlands is lighter, often gravelly, reasonably fertile where deep enough, and commands the highest prices around Kendal.

On the east coast of the Furness peninsula there is an area of stiff bluish clay, the colour doubtless being due to the fact that it is a local drift situated upon Carboniferous limestone. On the western side of the peninsula the clay has a lighter reddish or brownish colour, and is rather more sandy; on the west coast of Walney Island it is described as a red or brownish-red, sandy clay.

Boulder clay covers the central part of Cartmel and gives rise to a free-working soil on the limestone. In the north-eastern part of this region, especially between Windermere and Kendal, the boulder clay is not so extensive, occurring only as isolated drumlins. On each side of the mouth of the Kent there are areas free from drift where the soil is derived from the Carboniferous limestone. These areas are not suitable for arable farming because they are hilly, and they are usually well wooded. Areas relatively free from drift and having only a thin covering of soil are characteristic of the Furness Fells.

The largest areas of sandy soil occur south of Barrow, south of Ulverston, and in the Kent valley, especially in the vicinity of Kendal.

In the upper part of the Kent valley the soil is derived from the till or boulder clay, but near Kendal this passes into a fine gravelly deposit for which the name boulder clay is inappropriate. The division between the boulder clay and the gravel is very ill-defined. Similar gravelly soils are found in the Lune valley around Sedbergh.

Alluvial soils are very conspicuous and important in this region, being well developed along the margins of the large estuaries. The smaller inland patches of alluvial soils often occur in the interdrumlin hollows or on the sites of former tarns. Alluvium covers the floor of the Rusland valley separating Furness proper from Cartmel. This wide flat-bottomed valley reaches only 50 ft. above sea-level at Rusland village, and so affords a large area of low-lying, level, alluvial soil. A thick deposit of peat covers some parts of the valley-floor, and as this is cut the 'moss' is slowly reclaimed. The most important of the alluvial areas is the extensive one in the Lyth valley, drained by the river Gilpin. Although some of the alluvial areas tend to be rather gravelly, the soil here consists of sand and loam; this fact, together with the rigidly level and very low-lying nature of the valley (20 ft. above O.D.) makes the conditions excellent for farming. At various times large areas around the shores of Morecambe Bay have been reclaimed, and although all the reclamations have not been successful, the majority of those made when the railway was built have been successfully preserved from re-encroachment. They provide areas of fine, stoneless soil, easy to work, reasonably retentive, and they possess a great natural reserve of fertility.

It is of interest to speculate on the possibilities of the large alluvial areas which could be reclaimed if the mouth of the Duddon estuary were dammed, as has been suggested, primarily in order to facilitate communication between Furness and south Cumberland.

The Dome

Within the Dome there are three chief soil types derived respectively from drift, alluvium, and the underlying rock.

From the lowlands surrounding the Dome, long tongues of clay-drift extend into every valley, in most instances quite up to the dale-head itself. The limit depends, as a rule, not so much on the height above sea-level, as on the form of the ground. Allied to the drift deposits are the morainic mounds frequently occurring towards the heads of the valleys and giving an added air of dreariness to the landscape, e.g. in Ennerdale. In other instances the fact that they are more sandy and gravelly than the surrounding areas, consequently better drained, and slightly more elevated, determines the situation upon them of hamlets or farms.

Drift gradually becomes indistinguishable from weathered or decomposed rock at higher elevations. On steep slopes, exposures of bare rock are common, but elsewhere the soil is shallow, except where owing to gravity or rain-wash the depth is increased. Over the outcrops of

Skiddaw Slate the soil is often shallow, and this rock weathers into small particles unlike that of the volcanic rocks.

Smith [2] has shown that glacier lakes occupied the lower ends of all the larger valleys of the Dome, and that in Wasdale and Ennerdale their sites were to the west of the present lakes, which only came into being after the withdrawal of the valley glaciers. The resulting effect of these lakes on the soil has been to leave areas of sand and gravel (deltas and beaches) and fine clay (lake-beds) on the margin of the Dome, especially near the mouths of the valleys opening to the Irish Sea.

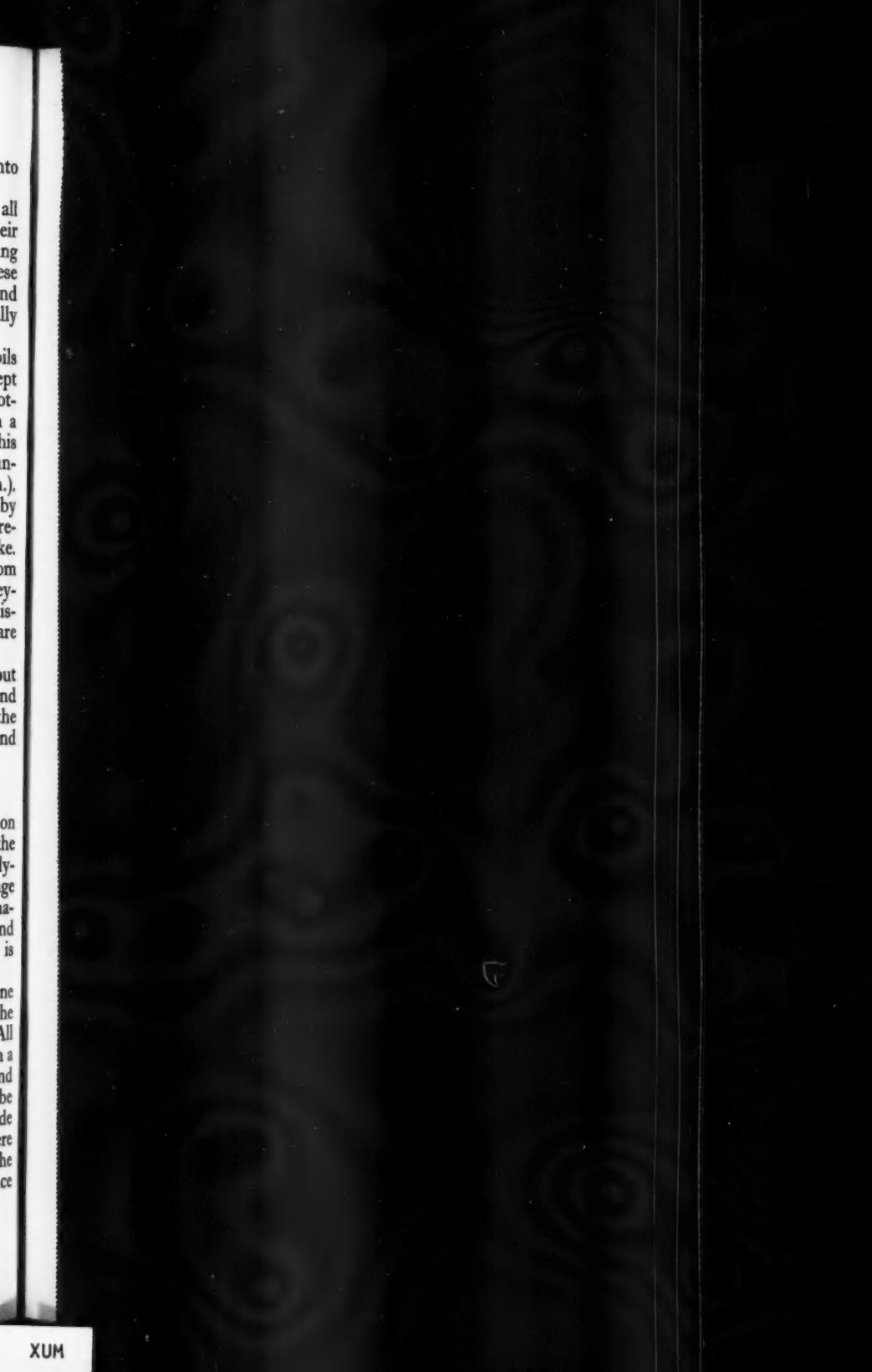
In all the valleys, but especially in the wider ones, the alluvial soils are conspicuous. They form the most useful agricultural areas, except where they are waterlogged, e.g. near Seathwaite, where the road, footpaths, and all buildings avoid the alluvial flat; a significant fact in a mountain valley where such ground is usually invaluable, and yet in this particular instance not quite unexpected when one remembers the unenviable rainfall record of Seathwaite (mean annual rainfall 122 in.). Farther north in the same valley are other former lake-sites indicated by alluvium. In the branch valley of Newlands, lake-muds exist and the present limit of cultivation marks almost exactly the former limits of the lake. Although these areas provide a well-mixed soil, relatively free from boulders, these advantages are offset by the fact that much of the valley-land is subject to flooding and is often difficult to drain. In some districts, e.g. in the Haweswater and Ullswater areas, farmsteads are usually found on the alluvial patches in the more elevated parts.

In brief, 'the present distribution of farms and hamlets throughout the district has been determined by the distribution of moraines and lake phenomena, the lake-floors providing excellent meadows and the moraines forming the well-drained sites of most of the houses and hamlets.' [3].

Conclusions

It will be seen that the important soil differences in the region described can be traced to the influence of parent material, and that the effects of the humid, equable climate cannot be neglected. The sharply-varying surface-forms also result in important differences in drainage and water conditions generally, and do much to determine the amenability to cultivation of any particular soil. Resistance to drought and retentiveness of water are largely a matter of soil texture, which is dependent upon the size of the constituent particles.

To the author's knowledge, no work on soil profiles has yet been done in the district, so that a study of the soil-forming processes and the effects of the parent material and cultivation can only be assumed. All that has been possible to do has been to study the soils of Cumbria on a geological basis and to make rough generalizations on the character and distribution of the soils. The outlines of the various soil types cannot be indicated with any degree of precision until a survey, such as that made in the Carlisle-Brampton area, is extended to the whole region. There are, of course, extreme instances of variations in soil type within the same field. The minor details are, however, of small practical importance



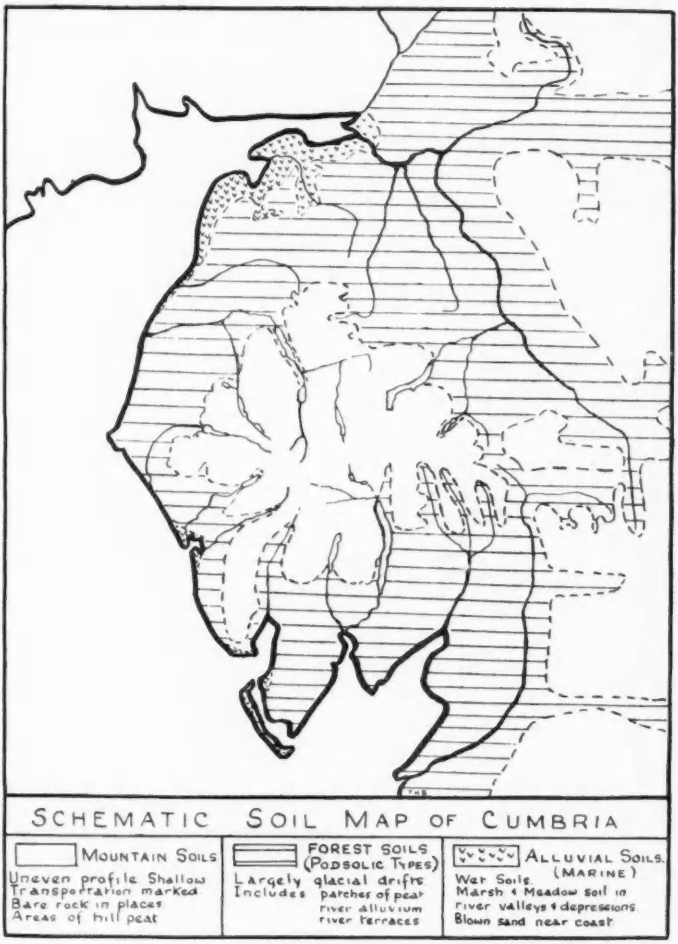

SCHEMATIC SOIL MAP OF CUMBRIA
MOUNTAIN SOILS
Uneven profile Shallow
Transportation marked
Bare rock in places
Areas of hill peat
FOREST SOILS (PODSOLIC TYPES)
Largely glacial drifts
Includes patches of peat
river alluvium
river terraces
ALLUVIAL SOILS (MARINE)
Wet Soils
Marsh & Meadow soil in
river valleys & depressions
Blown sand near coast

FIG. 1

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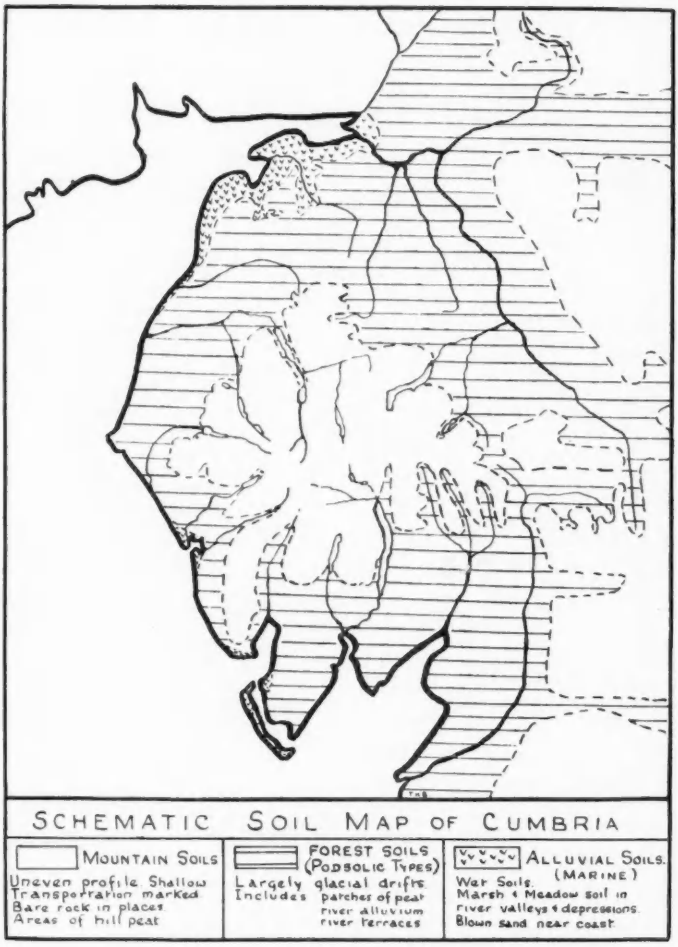
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FIG. 1

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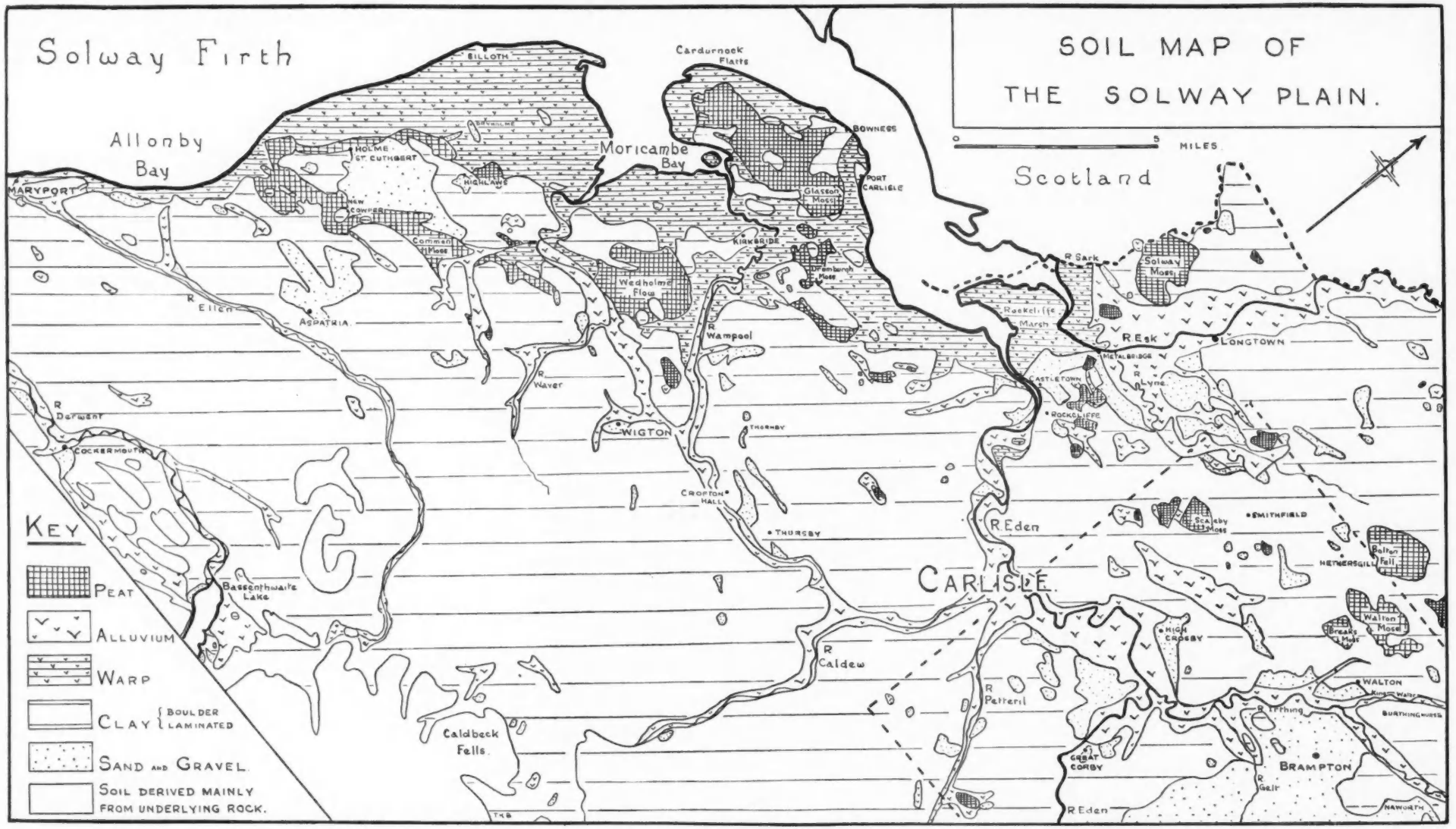

FIG. 2

NOTE. The key and scale on this map are also applicable to the other regional soil maps, i.e. FIGS. 3, 4, 5, 6
Portion of rectangle, in East, marked by broken line indicates the area for which a detailed soil survey is available. Rectangle continued also on FIG. 3

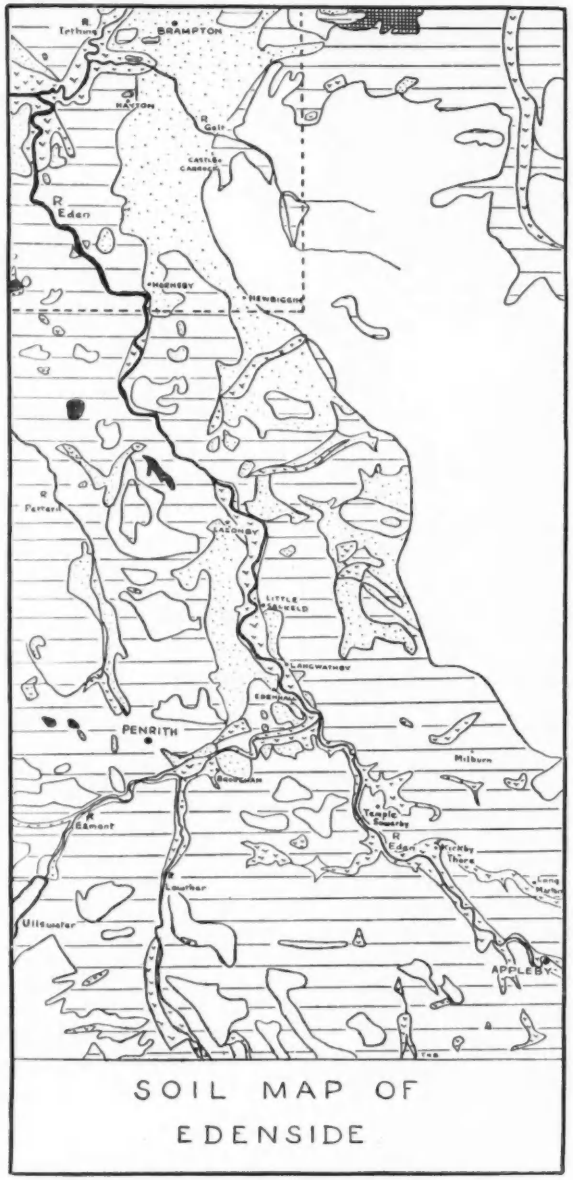

FIG. 3

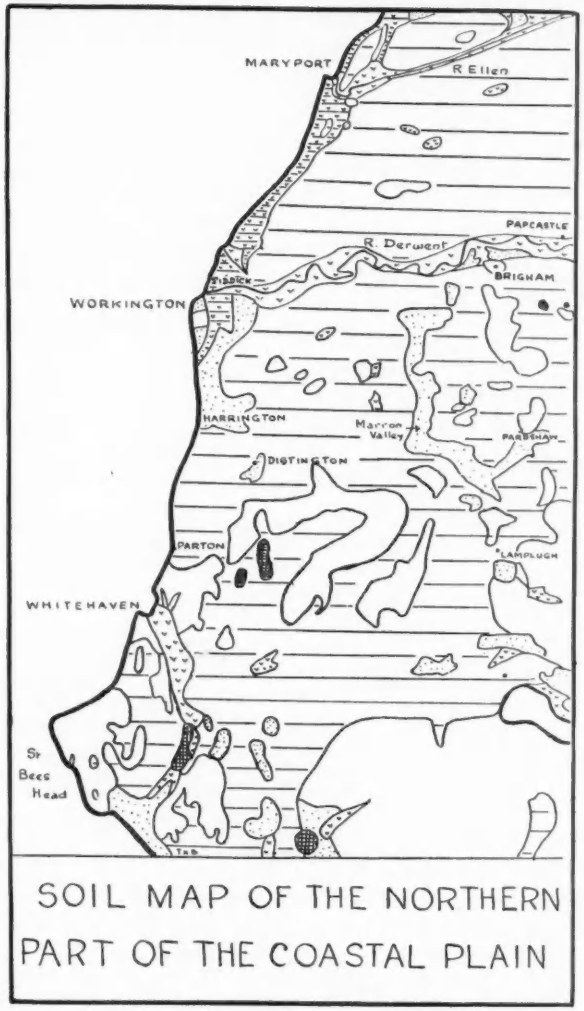

FIG. 4

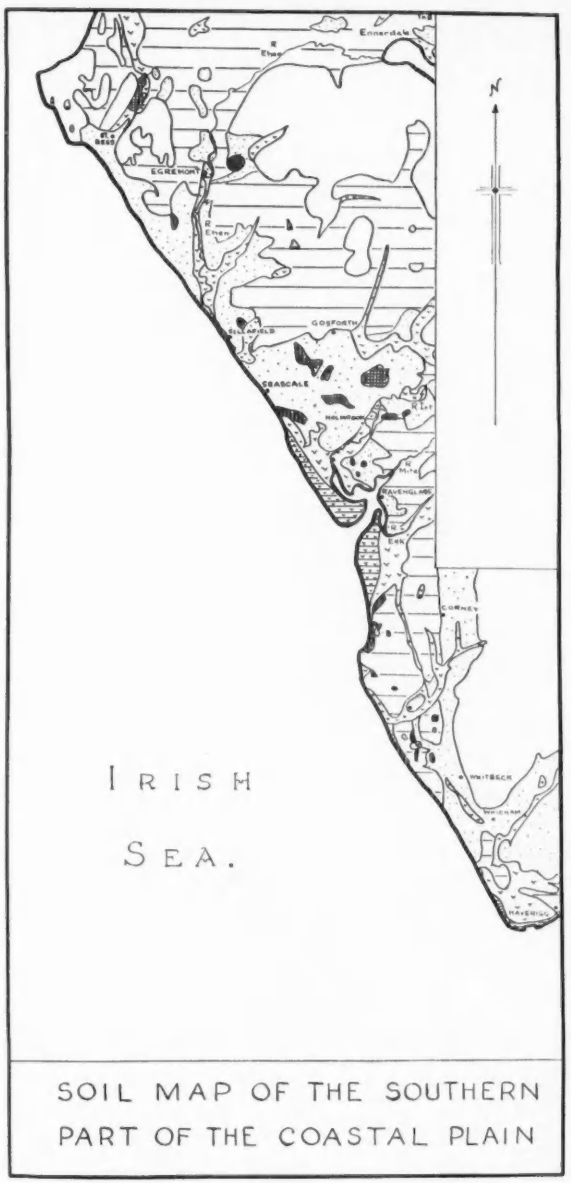

FIG. 5

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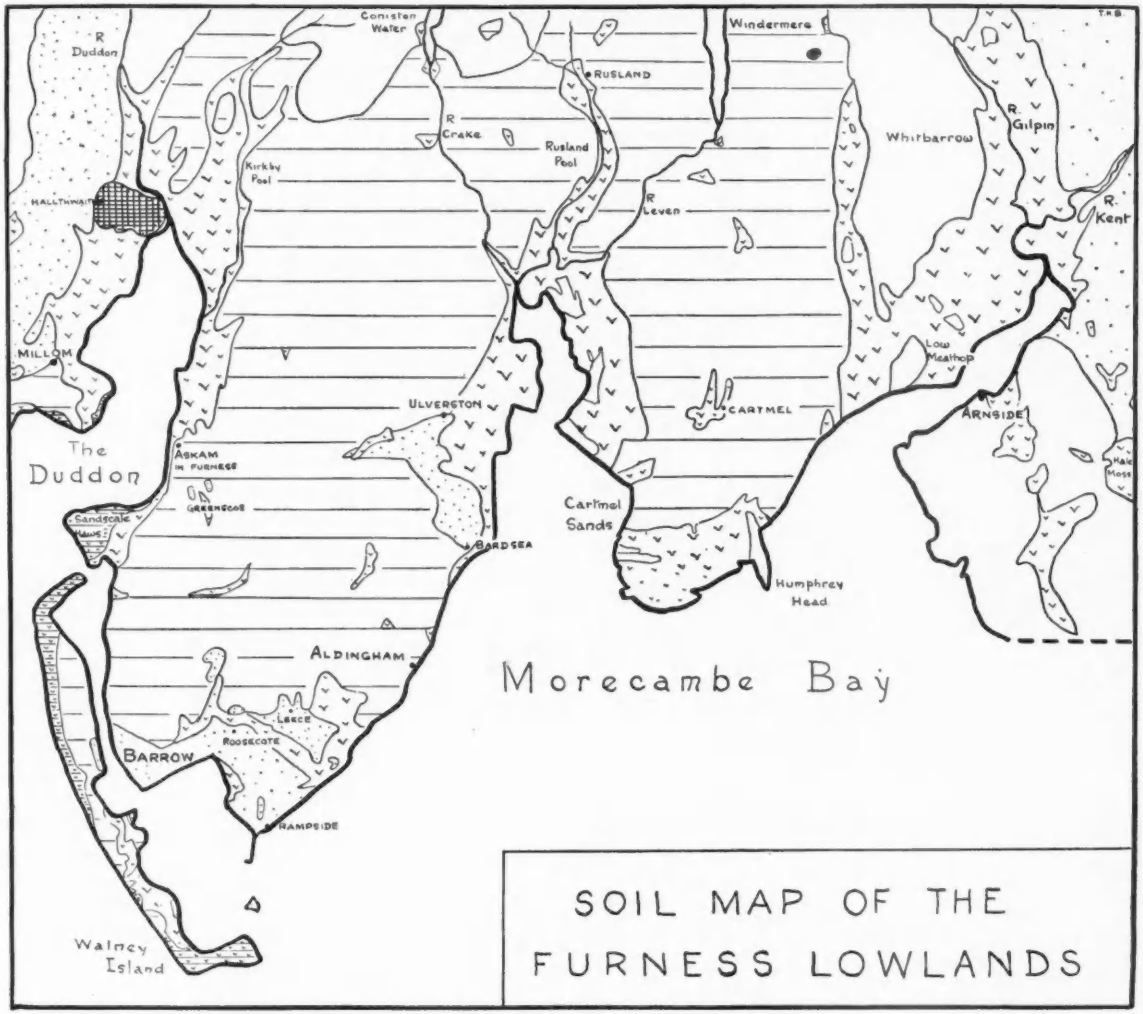
R Duddon
Coniston Water
Windermere
RUSLAND
R Crake
Rusland Pool
Kirkby Pool
R Leven
Whitbarrow
R Gilpin
R Kent
HALLTHWAITE
MILLOM
Low Meathop
ULVERSTON
CARTMEL
ARNSIDE
The Duddon
ASKAM IN FURNESS
GREENSCOE
Sandscale
BARDSEA
Cartmel Sands
Humphrey Head
ALDINGHAM
Morecambe Bay
LEECE
ROOSECOTE
BARROW
RAMPSIDE
Walney Island
SOIL MAP OF THE FURNESS LOWLANDS

FIG. 6

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in a regional study such as this, for the agricultural practice of any district is influenced in its evolution by several factors of which the soil is only one.

The study has, however, afforded a certain amount of information which will undoubtedly be of use in any study of the agriculture of Cumbria; and it should be especially useful in any comparison or classification of farming districts, like that attempted by Hanley, Boyd, and Williamson in the northern province [4].

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1. F. M. Trotter and S. E. Hollingworth, The Geology of the Brampton District, H.M.S.O., 1932.
[Plate IX is a soil map of the Brampton area. Chap. IX gives details of the soils shown on the map, with a table of analyses.]
2. B. Smith, Glaciation of Black Combe. Quart. J. Geol. Soc., 1912, **68**, 402. Glacier Lakes of Eskdale, ibid., 1922, **88**, 57.
3. A. Raistrick, A Preliminary Note on the Glaciation of Borrowdale, Cumberland. Geol. Mag., 1925, **62**, 279.
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XUM

MEAT-MEAL AS A SUPPLEMENTARY SOURCE OF PROTEIN FOR MILKING COWS ON PASTURE

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THIS paper outlines methods of grazing and supplementary feeding of milking cows at the State Research Farm, Werribee, where 75 to 90 pure-bred Red Poll and Friesian cows are milked daily. It shows that meat-meal supplies protein suitable to balance rations of home-grown fodders, such as cereal hay and grain, fed supplementary to pasture grass. The cows that received meat-meal also produced larger quantities of richer milk.

Management and Feeding of the Milking Cows on Pasture

The milking cows, which are divided into two herds, A and B, graze rotationally night and day throughout the year on 70 acres of top-dressed, irrigated pasture, subdivided into nine paddocks. The rotational grazing-cycle is completed in 28 days. This area of 70 acres includes 3 acres of headlands, and $2\frac{1}{3}$ acres of irrigation channels and drains from which only limited grazing is obtained. The pastures are well established and the principal species present are perennial rye-grass (*Lolium perenne*), prairie grass (*Bromus unioloides*), cocksfoot (*Dactylis glomerata*), white clover (*Trifolium repens*), and strawberry clover (*Trifolium fragiferum*). Herd A, consisting of the fresher and heavier-milking cows, grazes the paddocks ahead of herd B, which acts as a follower. The number of cows in herd A is determined by the number of bails available in the milking-shed (usually 47 to 49). The remaining cows are run in herd B. The paddocks grazed by herd A are usually rested for 2 days before being grazed by herd B.

The milking-shed is situated from 30 to 50 chains from the various pasture paddocks, and the cows are usually off the pastures for six hours each day. They are hand-milked at 5.15 a.m. and 3 p.m. daily, and are fed supplementary rations in the milking-bails throughout the year. In late spring it is customary to close two paddocks and cut them for hay in December. The lay-out of the pasture paddocks and their location relative to the farm-buildings are shown in Fig. 1.

In Fig. 2, histograms covering the two-year period from July 1935 to June 1937 show the average daily figures of each month for the milk-yield per cow, the milk-yield per acre, the number of cows carried per acre, and the amount of supplementary feed fed per acre for the pasture paddocks shown in Fig. 1. The average amount of pasture-growth per day is also shown, but these figures cover intervals of 28 days and were obtained from the plots shown in Fig. 1 between paddocks 5A and 5B. The pasture on these plots is similar to the pasture on paddock 5B. A lawn-mower was used to cut the plots every 28 days and the clippings

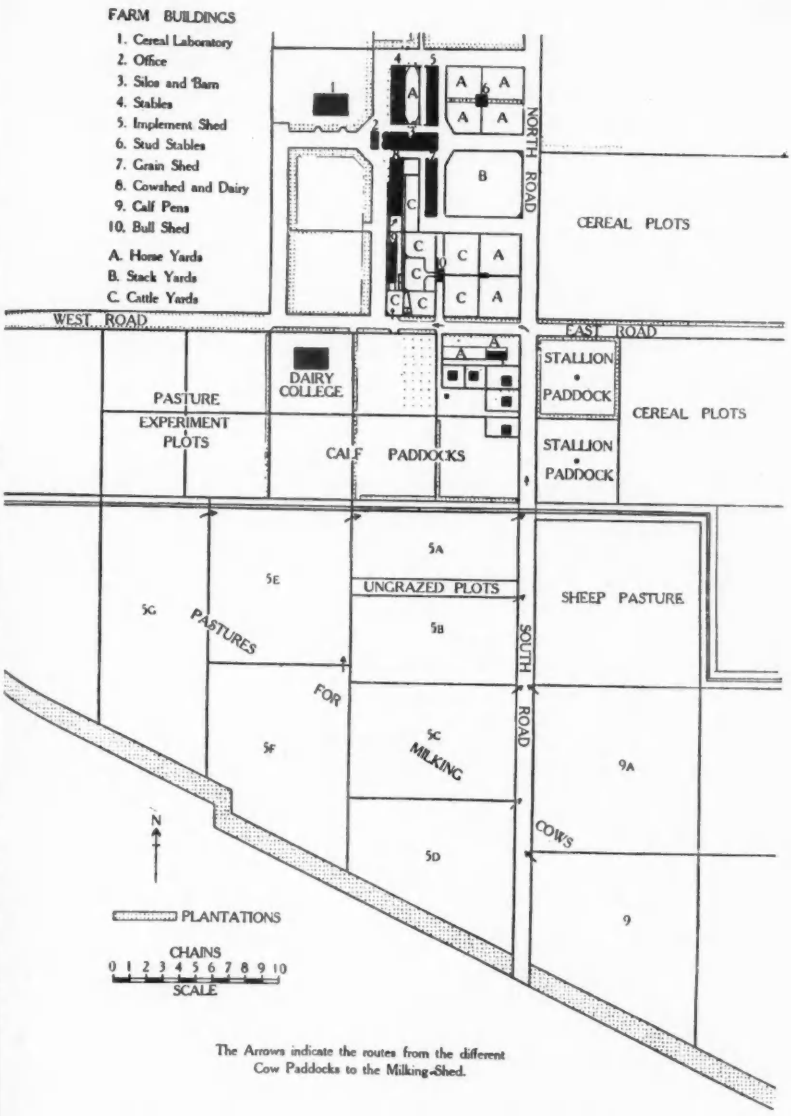

FIG. 1. Plan of the pasture paddocks and farm-buildings.

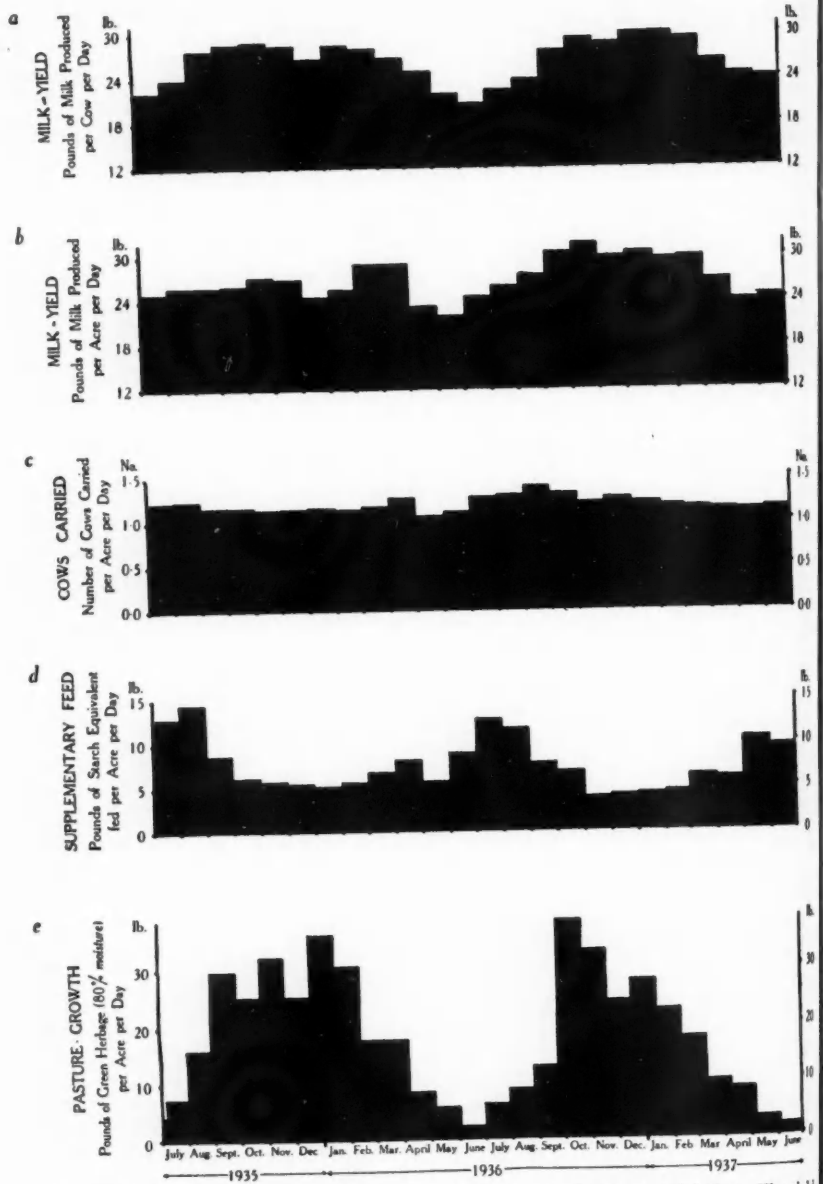

FIG. 2. Histograms showing per day, from July 1935 to June 1937, (*a*) the milk-yield per cow, (*b*) the milk-yield per acre, (*c*) the number of cows carried per acre, (*d*) the amount of supplementary feed fed per acre, and (*e*) the amount of pasture-growth per acre.

were collected, weighed, sampled, and tested for moisture-content. The weights were then standardized to contain 80 per cent. moisture.

The supplementary rations consist principally of cereal hay (chaffed), grain (ground), and, for a short period in 1935, silage, all of which are produced on the farm. Each cow is fed the same quantity of roughage, which is varied seasonally, but the grain and concentrate portion of the ration is measured out to each cow in proportion to her milk-yield. This is also increased and decreased with the season. Fig. 2*d*. shows that the supplementary rations are increased during the winter periods when pasture-growth is slow.

During spring, summer, and early autumn, insufficient stock are carried to keep the pastures grazed down, and when winter approaches there is an accumulation of pasturage which is grazed short during the winter [1]. This pasturage, which accumulates before the winter, varies in length from 3 in. upwards, and in stage of maturity. The more mature herbage in the flowering stage contains many dead leaves in its lower parts. The surplus growth in the spring is also controlled to a large extent by concentrating the cows on fewer paddocks and cutting the pasture on the other paddocks for hay. In December 1935, paddocks 5E, 5F, and 5G (then all one paddock) were cut for hay, and paddocks 5C and 5G in December 1936. In both cuts, the yield of hay was approximately 30 cwt. per acre. The subdivisions separating paddocks 5E, 5F, and 5G were made in September 1936. Stock other than the milking cows are frequently grazed in the paddocks. In the calculations, five sheep have been reckoned as being equal to one cow, and two horses as equal to three cows.

In Fig. 3, two combined graphs are shown. The upper line combines pasture-growth and supplementary feed with a deduction for the amount of grass cut for hay. The pasture-growth shown in Fig. 2*e* has been calculated in terms of pounds of starch equivalent per acre [2], and a correction has been made in the figures because paddock 5B, although covering only 7½ per cent. of the total grazing-area, produced 10 per cent. of the total milk-yield and carried the same percentage (10) of the cows. Paddock 5B is a superior pasture paddock, as also is paddock 9.

The lower curved line combines the number of cows carried and the weight of milk produced per acre. Each of the graduations on the vertical axis represents 7 lb. of starch equivalent, one cow, or 20 lb. of milk. This graph shows how, by suitable supplementary feeding, combined with pasture and herd management, steady production can be maintained throughout the year.

During 1936–7 the production-curve and the curve showing available food-material follow one another more closely, and this is attributed mainly to (i) the subdivision of the 26½-acre paddock into paddocks 5E, 5F, and 5G, and (ii) the addition of meat-meal to balance the supplementary rations.

Meat-Meal as a Cheap and Valuable Source of Protein

Experiments [3] have been conducted to show the value of meat-meal and of blood- and fish-meals as cheap sources of protein. In Australia,

although knowledge of them is becoming general, it is not as yet widely applied.

The majority of meat-meals available in Australia are of the dry-rendered type, and different brands, sold as meat-meal, liver-meal, &c., contain various percentages of protein and ash. Blood-meal, which is manufactured by a different process, is also available, but fish-meal is not obtainable in commercial quantities.

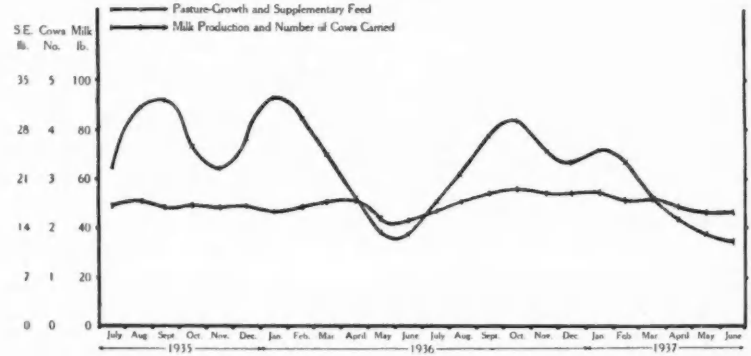
Pasture-Growth and Supplementary Feed
Milk Production and Number of Cows Carried
S.E. lb.
Cows No.
Milk lb.
35 5 100
28 4 80
21 3 60
14 2 40
7 1 20
0 0 0
July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. April May June
1935
1936
1937

FIG. 3*a*. Combined graphs showing from July 1935 to June 1937 (i) pasture-growth and supplementary feed as starch equivalent, and (ii) the number of cows carried and the weight of milk produced, per acre per day.

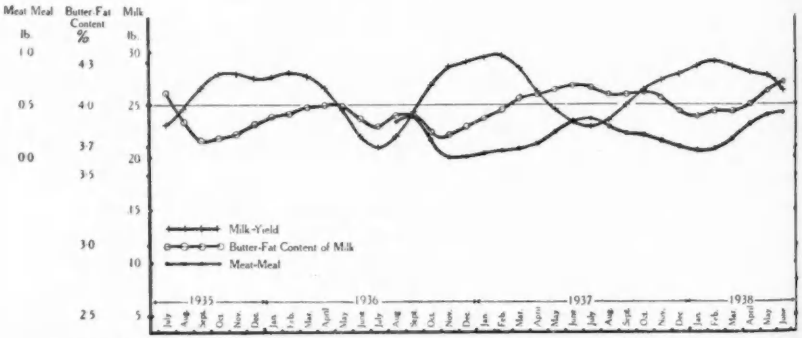

FIG. 3*b*. Graphs showing from July 1935 to June 1938 (i) the average daily milk-yield per cow, (ii) the average butter-fat content of the milk, and (iii) from August 1936 to June 1938, the daily quantity of meat-meal fed per cow.

In countries where hand-feeding of sheep and beef cattle is practised during the winter months, meat-meal is more widely used as a source of protein, and striking results from its use have been obtained, particularly by McCall and Hackedorn [4], and Peters [5]. In Australia, the Australian Estates Company [6] has found blood-meal to be a superior source of protein for supplementary feeding of sheep during drought.

The significant results obtained from experimental feeding of meat-meal

to pigs and poultry have long been recognized, and now they are being more widely applied.

A Feeding Experiment with Meat-Meal

During June and July 1935, a feeding-trial with meat-meal was conducted with the milking cows at Werribee. For several years previously the writer was of opinion that the relatively bare winter pastures did not supply sufficient protein to balance the large rations of cereal chaff, grain, and other concentrates fed to the milking cows as supplements to the sparse pasturage. In this experiment, the meat-meal not only increased the milk-yields, but also the butter-fat content of the milk. Since then meat-meal has been regularly and successfully added to the supplementary rations of all the milking cows on the farm.

No taints in the milk have resulted, nor has the quality of the milk and cream been impaired in any way by meat-meal feeding. Archibald [7] found that as much as 17 per cent. of meat-meal could be fed in the concentrate ration without causing any taint in the milk.

All the Friesian cows in herd A were used in the experiment. They were divided into two groups, cows being selected alternately from a list containing their names in the order in which they had calved. The first group containing seven cows was fed 1½ lb. of meat-meal daily, whilst the second group containing six cows was used as a control. The meat-meal was not intended as additional feed but, as the cows were being fed 1 lb. of concentrate for each 2¾ lb. of milk produced, it so happened that the average weight of concentrate, excluding meat-meal, fed to each cow in both groups was the same. The concentrate mixture contained bran, wheat, barley, oats, and peas in the proportions shown in Table 3*a*.

Effect on milk-yield.—The milk from each cow was weighed and recorded at each milking. Butter-fat determinations were made on three composite samples from each cow, one being collected before feeding meat-meal, another during the feeding, and the third after the feeding of meat-meal was discontinued.

It has been the practice at Werribee to take the average daily milk-yield of cows over five consecutive day-periods rather than the average for each day, as this evens out minor variations resulting from changes to a fresh paddock, short changes in weather, &c., and, when considering the combined herds A and B, changes due to introducing new cows and turning out dry ones. The average milk-yields shown are all for five consecutive day-periods.

The cows receiving meat-meal increased their milk-yields during the experiment and, although they were producing 2·2 lb. more milk per cow daily prior to the experiment, they were giving 5·3 lb. more milk than the controls at the close of the experiment. The combined herds A and B showed very little variation in milk-yield during this period. Details of the changes in milk-yield of the cows in the meat-meal group, the control group, and the combined herds A and B are shown in Table 1.

Effect on butter-fat content of milk.—The average butter-fat content of milk from the control cows and milk from the combined herds A and B are in agreement (Table 2), but the average butter-fat content of milk

received from the cows that were given meat-meal rose 0·47 per cent. while the meal was being fed; it dropped back, however, to normal when the meal was discontinued.

TABLE 1. *Effect of Feeding Meat-Meal on Milk-Yield*

Date 1935	Average daily milk-yields in pounds		
	Cows receiving meat-meal	*Control cows*	*All cows (80) in herds A and B*
June 10–14	..	..	22·2
June 15–19	..	..	21·9
June 20–24	32·2	30·0	22·2
June 25–29	31·7*	28·8	22·2
June 30–July 4	31·2*	28·5	21·7
July 5–9	34·0*	29·6	21·9
July 10–14	34·8*	29·4	22·1
July 15–19	34·1	28·8	22·2
July 20–24	..	..	22·3
July 25–29	..	..	22·8

* The meat-meal was fed from June 25 to July 14.

TABLE 2. *Effect of Feeding Meat-Meal on Butter-Fat Content of Milk*

Time of collecting samples	Average percentage of butter-fat in milk from:		
	Cows receiving meat-meal	*Control cows*	*All cows (80) in herds A and B*
Prior to feeding meat-meal	3·66	3·36	4·28
While feeding meat-meal	4·13	3·24	4·15
After feeding of meat-meal was stopped	3·50	3·37	4·21

Rations fed.—The supplementary rations fed to, and the calculated food-requirements of, the Friesian cows during the meat-meal feeding experiment are shown in Tables 3*a*, *b*.

TABLE 3*a*. *Supplementary Rations Fed during the Experiment*

Foodstuff	Supplementary rations per cow per day in pounds					
	Cows receiving meat-meal			*Control cows*		
	Weight	*S.E.* [2]	*P.E.* [2]	*Weight*	*S.E.* [2]	*P.E.* [2]
Silage (oat)	2·7	0·32	0·02	2·7	0·32	0·02
Chaff (oat and wheat)	14·3	5·22	0·56	14·3	5·22	0·56
Bran	0·6	0·26	0·05	0·6	0·26	0·05
Wheat	6·3	4·60	0·52	6·3	4·60	0·52
Barley	0·4	0·28	0·03	0·4	0·28	0·03
Oats	0·5	0·31	0·04	0·5	0·31	0·04
Peas	3·0	2·07	0·55	3·0	2·07	0·55
Meat-meal	1·5	1·26	0·82	..	..	..
Total	29·3	14·32	2·59	27·8	13·06	1·77
Nutritive ratio	1 : 5·5			1 : 7·4		

Results.—The average live-weight of the cows receiving meat-meal was 1,186 lb., whereas that of the control cows was 1,083 lb. The calculated food-requirements do not allow for changes in live-weight caused by growth, pregnancy, or improvement in condition. Exposure to adverse weather and energy required for moving about and grazing are unknown factors that are not allowed for. The amount of grass grazed by the cows is also unknown.

TABLE 3*b*. *Food-Requirements of the Cows* [2]

Requirement for	*Cows receiving meat-meal*		*Control cows*	
	S.E.	*P.E.*	*S.E.*	*P.E.*
	lb.	lb.	lb.	lb.
Maintenance . . .	6·9	0·69	6·5	0·65
Milk	9·3	2·13	6·6	1·59
Total . . .	16·2	2·82	13·1	2·24

The tables indicate that the control cows, receiving a supplementary ration with a nutritive ratio of 1 : 7·4, consumed as much energy in the form of starch equivalent as was calculated to cover their requirements, but there was a deficiency (0·47 lb.) of protein equivalent. To make up this deficiency the cows would have required 10·4 lb. pasturage daily, and this would have supplied 1·5 lb. starch equivalent above their calculated requirements.

The cows receiving meat-meal were given, in the form of supplementary feed, 1·9 lb. less starch equivalent and 0·23 lb. less protein equivalent than their calculated requirements. To make up this deficiency of starch equivalent, the cows would have required 13·5 lb. pasturage, whereas to make up the deficiency of protein equivalent they would have required only 5·1 lb. pasturage daily. Possibly similar results could have been obtained by feeding a smaller quantity of meat-meal.

In August 1936, feeding of meat-meal to all the milking cows was commenced, and since then quantities varying from 0·02 lb. in late spring to 0·56 lb. in mid-winter have been fed daily to each cow. Increases in milk-yield, particularly during the winter months, and in butter-fat content of the milk, have been recorded, whilst improvement in the health and condition of the cows has also been observed.

The average daily milk-yields per cow and the butter-fat content of the milk from July 1935 until June 1938, and the daily amount of meat-meal fed per cow per day since August 1936, are shown graphically in Fig. 3*b*.

Summary and Conclusions

The milk-yield of a herd can be maintained fairly constant throughout the year by careful herd- and pasture-management and by suitable supplementary feeding.

The feeding of 1½ lb. of meat-meal per cow daily during June and July 1935 to seven cows raised their milk-yield and increased the butter-fat content of their milk, whereas the milk-yield, and its butter-fat content, of six control cows decreased during the same period.

Since August 1936, small amounts of meat-meal, varying from 0·02 to 0·56 lb. per cow daily, have been fed to all the milking cows. This practice has increased the milk-yield of the herd, particularly the winter yield, and the butter-fat content of the milk, thus supporting the results from the experiment conducted in 1935.

The meat-meal has not imparted any taint to the milk, and since it has been fed the cows have been in better health and condition.

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THE ROTHAMSTED FIELD EXPERIMENTS ON BARLEY 1852–1937

Pt. III. THE COMPOSITION AND QUALITY OF THE BARLEY GRAIN

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The Factors determining the Composition of Barley Grain

THE four important groups of constituents of barley grain are: (1) starch; (2) the celluloses and allied compounds; (3) the proteins and other nitrogen compounds; and (4) the mineral constituents. The celluloses form the cell walls, whilst the starch and protein are the chief cell contents.

Unfortunately the starch and hemicelluloses are so similar in chemical reaction that it is not possible to discriminate sharply between them. Up to the present, therefore, no method is known whereby the amount of starch in the grain can be satisfactorily determined.

The proteins are chiefly hordein and glutelin, with some albumin and salt-soluble nitrogen compounds. The relative amounts of these different compounds were shown by L. R. Bishop[1] to be closely related to the total amount of nitrogen in the grain, so that for any given variety the proportion can be deduced directly from the nitrogen-content. A closer approximation is obtained by basing the estimate on the weight of nitrogen per grain than on the percentage in the dry matter.

Obviously the higher the proportion of nitrogen compounds the lower must be the proportion of the other constituents, and Bishop has shown that these also are related quantitatively one to the other. He has deduced a regression equation whereby it is possible to predict with considerable accuracy the amount of brewer's extract—which depends on the amount of fermentable carbohydrate—yielded by different samples of barley, from a knowledge of the nitrogen-content and the weight of 1,000 corns. These two quantities have, therefore, been studied in some detail.

The Nitrogen-content of Barley Grain

Effect of soil type

1. *Barley grown continuously.*—The marked effect of soil conditions on the nitrogen-content of barley grain is shown by a comparison of the results obtained at Rothamsted and at Woburn on different soil types with similar manurial treatment. The results are given in Table 1.

The average nitrogen-content of the barley was higher at Woburn than at Rothamsted on all plots except that receiving farmyard manure, and the variation of nitrogen-content between fertilizer treatments was

[1] For a summary and full discussion of Bishop's papers published from Rothamsted under the Institute of Brewing Research Scheme see [1].

also greater at Woburn. The variation between seasons, of which the standard errors given in Table 1 are a measure, was consistently greater at Woburn than at Rothamsted, but the differences are small, nor are there any considerable differences between fertilizer treatments in seasonal variability.

TABLE 1. *Nitrogen-content of Barley grown continuously on Different Soils with Similar Manurial Treatment*

	Rothamsted, Hoosfield Heavy soil (1893–1928)			*Woburn, Stackyard field Light soil (1883–1926)*		
Treatment	*Average yield of grain cwt. per acre*	*Average Nitrogen-content per cent. of dry weight*	*Standard error of a single year*	*Average yield of grain cwt. per acre*	*Average Nitrogen-content per cent. of dry weight*	*Standard error of a single year*
Unmanured	5·2	1·48	±0·17	6·1	1·82	±0·18
Minerals only, no nitrogen	7·9	1·51	±0·20	7·6	1·74	±0·21
Nitrate of soda only	11·0	1·68	±0·24	10·6	2·05	±0·25
Sulphate of ammonia only	9·3	1·67	±0·23	7·7	1·98	±0·24
Minerals + nitrate of soda	17·6	1·57	±0·21	14·4	1·84	±0·27
Minerals + sulphate of ammonia	17·4	1·54	±0·18	8·9	1·92	±0·25
Farmyard manure	20·0	1·84	±0·17	16·4	1·84	±0·22

2. *Barley grown in rotation.*—The results of experiments made on barley grown in rotation at other centres under the Institute of Brewing scheme in the years 1922–6 are given in Table 2.

TABLE 2. *Effect of Soil Type on the Nitrogen-content of Barley grown in Rotation. Institute of Brewing Experiments, 1922–6*

			Number of experiments in which the average nitrogen percentage was:			
Nature of soil	*Mean yield of grain cwt. per acre*	*Mean Nitrogen per cent. in grain*	*Below 1·45*	*1·45–1·65*	*1·65–1·8*	*Above 1·8*
Chalk	22·6	1·46	2	2	1	..
Light and medium loams	20·2	1·53	8	13	6	1
Heavy loam	16·0	1·62	..	5	2	..
Fen	26·2	1·73	..	1	1	1
Light sand	13·1	1·78	1	3	1	5

The fen soils gave high yields of grain of high nitrogen-content, but for the other soil types the nitrogen-contents are in the inverse order of the yields. Chalk soils and light loams gave fairly high yields and

low nitrogen-contents; the heavy loams gave lower yields and higher nitrogen-contents. The light sandy soils with the lowest yields of all gave the highest nitrogen-contents.

The heavy loams give substantially the same nitrogen-content as the heavy soil of Hoosfield, and the sands give similar results to those obtained at Woburn (Table 1), indicating that the nitrogen-content is not much affected by the way in which the barley is grown: whether continuously or in rotation.

The range of variation between seasons and centres for each soil type is also shown in Table 2. As in the comparison of the continuously grown barley at Rothamsted and Woburn (Table 1), the variation was less on the heavy and medium loams than on the light sand. Thus weather conditions have a greater influence on the nitrogen-content of barley grown on a light sandy soil than on that of barley grown on a medium or heavy loam.

3. *Variations of nitrogen-content in different parts of the same field.*— Wide variations in the nitrogen-content of the grain may occur in different parts of the same field. This is well illustrated by an experiment carried out in Foster's field, Rothamsted, in 1932. The average nitrogen-content of Plumage Archer barley, sown early or sown late, for all fertilizer treatments, within the four replicate blocks of the experiment are shown in Table 3.

TABLE 3. *Plumage Archer Barley, Rothamsted, Foster's Field, 1932*

	Sown early				*Sown late*			
Block:	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
Nitrogen in grain, per cent. . . .	1·87	1·65	1·61	1·64	2·02	1·79	1·79	1·76
Yield of grain, cwt. per acre . . .	35·9	31·4	25·6	26·9	27·8	26·8	21·5	23·9

The values range between 1·87 and 1·61 for the early sowing and between 2·02 and 1·76 for the late sowing, variations far greater than those produced by differences in manuring and time of sowing on the same plots (p. 203).

To the eye the different areas of soil appeared alike, and the field would have been judged by any practical man as a good one for field trials. The results suggest that the nitrogen-content of the barley grain, being so easily measured and not affected by bird-damage or harvest losses, could be used as a simple test for soil heterogeneity.

It should be pointed out, however, that heterogeneity with respect to nitrogen percentage in grain is not necessarily identical with heterogeneity with respect to yield. In the present experiment high yield is associated with high nitrogen percentage, but where heterogeneity with respect to yield is due to variations in factors other than nitrogen supply, an inverse relation between yield and nitrogen percentage might be expected, such as was found for different soil types.

The Relation between Nitrogen-content of the Grain and Yield

The experiments on barley grown continuously at Rothamsted and Woburn show a negative correlation between nitrogen percentage in the grain and yield on any given plot (Table 4).

TABLE 4. *Relation between Nitrogen Percentage in the Grain and Yield* [6]

	Plot	*Mean Yield of grain cwt. per acre*	*Mean Nitrogen per cent.*	*Regression coefficient of nitrogen percentage on yield in cwt. per acre*
*Hoosfield, Rothamsted, 1893–1928**				
Unmanured . . .	1–O	5·0	1·47	−0·0255† ±0·0114
Sulphate of ammonia only.	1–A	9·0	1·68	−0·0290† ±0·0100
Complete minerals . .	4–O	7·5	1·51	−0·0246† ±0·0088
Minerals and sulphate of ammonia . . .	4–A	17·0	1·54	−0·0113 ±0·0058
Farmyard manure . .	7–2	18·3	1·85	−0·0006 ±0·0048
Stackyard field, Woburn, 1882–1926‡		*Bushels per acre*		*Bushels per acre*
Unmanured . . .	1	12·2	1·83	−0·0085 ±0·0055
Nitrate of soda only. .	3	21·2	2·05	−0·0096 ±0·0053
Complete minerals . .	4b	15·6	1·74	−0·0092 ±0·0053
Minerals and sulphate of ammonia . . .	5a	15·2	1·92	−0·0079 ±0·0061
Minerals and nitrate of soda	6	29·5	1·84	−0·0136† ±0·0049
Minerals and nitrate of soda (alternate years) . .	9	34·8	2·03	−0·0099† ±0·0048
Farmyard manure . .	11b	33·7	1·83	−0·0078† ±0·0038

* Partial regression coefficients after the elimination of trend and the effects of varying sowing-date and April–June rainfall. 1912 (fallow) and 1913 omitted.
† Significant. ‡ Trend eliminated.

The Rothamsted and Woburn results agree in showing that an increase in yield of grain of 1 cwt. per acre was accompanied by a decrease in the nitrogen percentage of about 0·02. The regression coefficients for Woburn vary little between plots, though not all are significant. At Rothamsted, however, the coefficients for the high-yielding plots 4–A and 7–2 are smaller than for the other plots; indeed, the farmyard-manure plot, 7–2, shows scarcely any decline of nitrogen percentage with increasing yield.

An examination of the results of 47 experiments in the Institute of Brewing series during the years 1922–6 failed to show any definite relation between nitrogen-content of the grain and yield. The regression coefficient of mean nitrogen percentage on mean yield of grain in cwt. per acre, −0·0014 ±0·0054, though negative, was far from significant.

In general, in conditions where the yield is determined mainly by factors other than the level of nitrogen supply, a negative relation between nitrogen-content and yield is found. The seasonal variation of

yield in the continuous barley experiments at Rothamsted and Woburn is determined mainly by climatic factors. Similarly the inverse relation between nitrogen percentage and yield shown in Table 2 for the different soil types, excluding the fen soils, suggests that the differences in yield between the soil types are due to variation in factors such as water-supply, aeration, and soil depth, and not to the amount of nitrogen available for the plant. On the other hand, where the nitrogen supply is the most important factor in determining yield, as in the comparison of fen soils with the other types (Table 2), and presumably in the example of variation within a field given in Table 3, the relation between nitrogen-content and yield is positive.

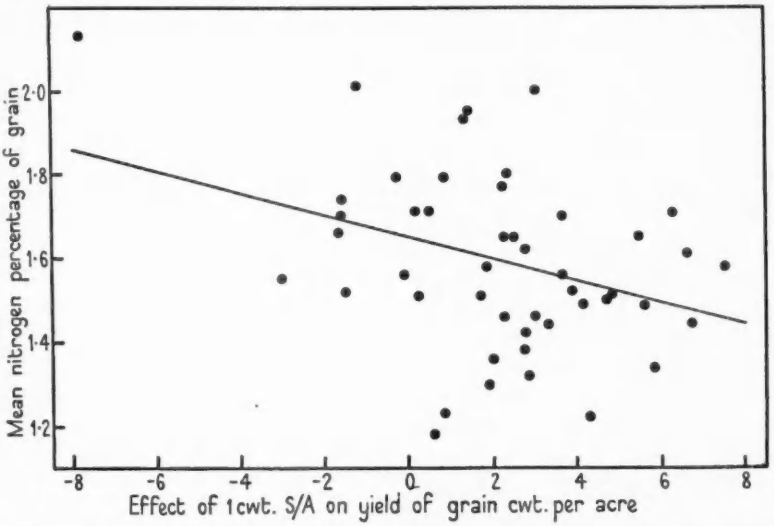

FIG. 1. The relation between nitrogen percentage in the grain and the effect of sulphate of ammonia on the yield of grain (Institute of Brewing Experiments, 1922–6). The regression line has the equation $(y-1{\cdot}59) = 0{\cdot}028\,(x-2{\cdot}14)$, where y = mean nitrogen percentage in the grain, and x = increase of yield of grain in cwt. per acre produced by 1 cwt. sulphate of ammonia per acre.

The nitrogen-content of the grain is related to the effectiveness of the nitrogenous fertilizer in increasing yield. This is clearly shown by the Institute of Brewing series of experiments (Fig. 1). The regression coefficient of the percentage of nitrogen in the grain for the mean of all fertilizer treatments on the increment of grain yield in cwt. per acre produced by 1 cwt. of sulphate of ammonia per acre was $-0{\cdot}028 \pm 0{\cdot}011$, and was significant. Thus, when the effectiveness of the fertilizer was high, the nitrogen-content of the grain tended to be low, and vice versa. High effectiveness of the nitrogenous fertilizer indicates that the supply of nitrogen in the soil is low compared with the intensity of other factors which determine yield, so that the quantity of nitrogen taken up by the plant, and the part of it passed to the grain, is small relative to the total

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Minerals and nitrate of soda (alternate years) . .	9	34·8	2·03	−0·0099† ±0·0048
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† Significant. ‡ Trend eliminated.

The Rothamsted and Woburn results agree in showing that an increase in yield of grain of 1 cwt. per acre was accompanied by a decrease in the nitrogen percentage of about 0·02. The regression coefficients for Woburn vary little between plots, though not all are significant. At Rothamsted, however, the coefficients for the high-yielding plots 4–A and 7–2 are smaller than for the other plots; indeed, the farmyard-manure plot, 7–2, shows scarcely any decline of nitrogen percentage with increasing yield.

An examination of the results of 47 experiments in the Institute of Brewing series during the years 1922–6 failed to show any definite relation between nitrogen-content of the grain and yield. The regression coefficient of mean nitrogen percentage on mean yield of grain in cwt. per acre, $-0{\cdot}0014 \pm 0{\cdot}0054$, though negative, was far from significant.

In general, in conditions where the yield is determined mainly by factors other than the level of nitrogen supply, a negative relation between nitrogen-content and yield is found. The seasonal variation of

yield in the continuous barley experiments at Rothamsted and Woburn is determined mainly by climatic factors. Similarly the inverse relation between nitrogen percentage and yield shown in Table 2 for the different soil types, excluding the fen soils, suggests that the differences in yield between the soil types are due to variation in factors such as water-supply, aeration, and soil depth, and not to the amount of nitrogen available for the plant. On the other hand, where the nitrogen supply is the most important factor in determining yield, as in the comparison of fen soils with the other types (Table 2), and presumably in the example of variation within a field given in Table 3, the relation between nitrogen-content and yield is positive.

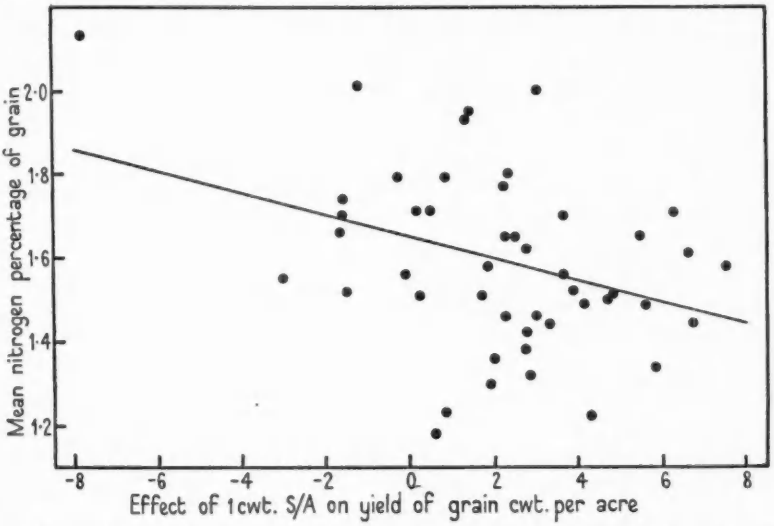

FIG. 1. The relation between nitrogen percentage in the grain and the effect of sulphate of ammonia on the yield of grain (Institute of Brewing Experiments, 1922–6). The regression line has the equation $(y-1{\cdot}59) = 0{\cdot}028\,(x-2{\cdot}14)$, where y = mean nitrogen percentage in the grain, and x = increase of yield of grain in cwt. per acre produced by 1 cwt. sulphate of ammonia per acre.

The nitrogen-content of the grain is related to the effectiveness of the nitrogenous fertilizer in increasing yield. This is clearly shown by the Institute of Brewing series of experiments (Fig. 1). The regression coefficient of the percentage of nitrogen in the grain for the mean of all fertilizer treatments on the increment of grain yield in cwt. per acre produced by 1 cwt. of sulphate of ammonia per acre was $-0{\cdot}028 \pm 0{\cdot}011$, and was significant. Thus, when the effectiveness of the fertilizer was high, the nitrogen-content of the grain tended to be low, and vice versa. High effectiveness of the nitrogenous fertilizer indicates that the supply of nitrogen in the soil is low compared with the intensity of other factors which determine yield, so that the quantity of nitrogen taken up by the plant, and the part of it passed to the grain, is small relative to the total

amount of dry matter assimilated, and consequently the nitrogen percentage of the grain is low. On the other hand, an addition of a nitrogenous fertilizer has little effect on yield when the natural supply of nitrogen in the soil is high, and in these conditions the amount of nitrogen passed to the grain is high relative to the dry matter assimilated.

Effect of Fertilizers on Nitrogen-content of the Grain

Nitrogenous Fertilizers

The effect of nitrogenous fertilizers on the nitrogen-content of barley is dependent on their effect on yield. A single dose of a nitrogenous fertilizer may so increase the yield that it actually decreases the percentage of nitrogen in the grain. On the other hand, the increased yield may just balance the additional nitrogen taken up, in which case the nitrogen-content remains unchanged; or the increased yield may be small relative to the additional uptake of nitrogen, and then the nitrogen-content is increased.

The experiments made on barley-growing farms at outside centres show that these three possibilities are all of common occurrence in practice:[1] in 50 experiments the effect on the percentage of nitrogen in the grain of a dressing of 1 cwt. of sulphate of ammonia per acre was as follows:

	Nitrogen percentage lowered	*Nitrogen percentage unaltered*	*Nitrogen percentage raised*
Number of experiments	14	16	20

The mean nitrogen-content of the grain was 1·60 per cent., and on the average of all the experiments the dressing of sulphate of ammonia increased the nitrogen-content significantly by 0·040±0·013 per cent.

When increasing quantities of a nitrogenous fertilizer are given, the effect of successive doses in increasing the yield of grain falls off more rapidly than the effect on nitrogen-uptake, so that although small dressings may have little effect on the nitrogen percentage in the grain, or may even reduce it, larger dressings may cause a considerable increase (Table 5).

TABLE 5. *Effect of Increasing Quantities of Sulphate of Ammonia on the Nitrogen Percentage in the Grain*

(*Six-Course Rotation Experiments*)

	None	*1 dose*	*2 doses*	*3 doses*	*4 doses**
Rothamsted 1931 (heavy soil)					
Nitrogen percentage in grain	1·67	1·64	1·69	1·52	1·80
Yield of grain, cwt. per acre	13·2	18·9	20·6	20·4	21·4
Woburn 1930 (light soil)					
Nitrogen percentage in grain	1·37	1·34	1·50	1·56	1·71
Yield of grain, cwt. per acre	13·6	18·9	18·2	20·7	23·0

* 1 dose = 0·15 cwt. nitrogen per acre.

[1] This accounts for an enormous amount of discussion in the literature as to whether nitrogenous fertilizers do or do not increase the nitrogen-content of the barley grain: for a summary see Hulton [2].

A consequence of this relation is that the effect of a nitrogenous fertilizer in increasing the nitrogen percentage in the grain is greater in conditions where the nitrogen percentage is already high than where it is low. This is confirmed by the results of the Institute of Brewing series of experiments shown in Fig. 2. The regression coefficient of the increase in nitrogen percentage produced by 1 cwt. sulphate of ammonia per acre, on the mean nitrogen percentage for all treatments was $0{\cdot}139 \pm 0{\cdot}057$, which is significant.

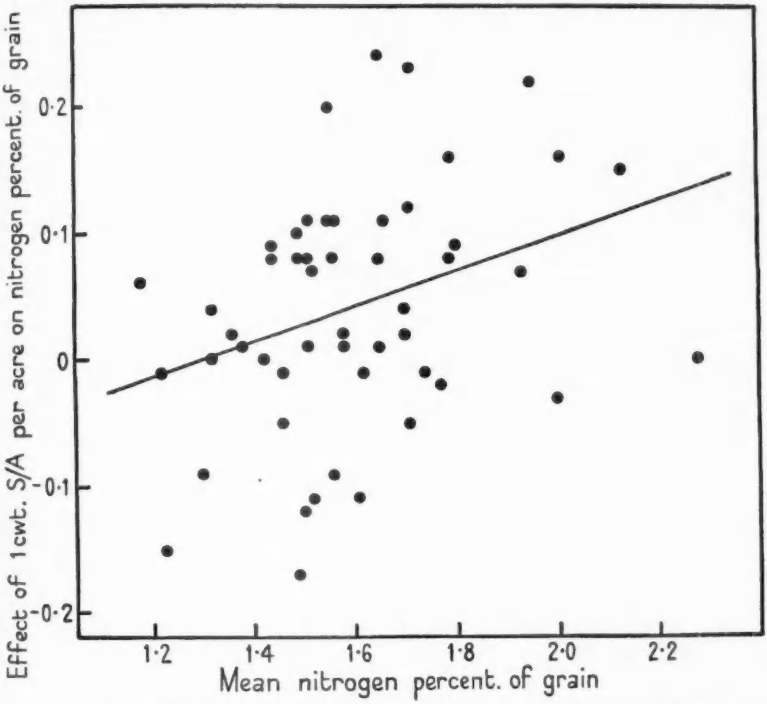

FIG. 2. The relation between the effect of nitrogenous fertilizer on the nitrogen percentage in the grain and the mean nitrogen percentage (Institute of Brewing Experiments, 1922–6).

The regression line has the equation $(y - 0{\cdot}040) = 0{\cdot}139\,(x - 1{\cdot}60)$, where y = the effect of 1 cwt. of sulphate of ammonia per acre on the nitrogen percentage in the grain, and x = mean nitrogen percentage in the grain.

It has been shown already that a high nitrogen percentage in the grain is found when the increase of yield produced by the nitrogenous fertilizer is small. In view of the relation established in the previous paragraph between the effect of a nitrogenous fertilizer on the nitrogen-content of the grain and the mean nitrogen percentage, it might be expected that the effects of the nitrogenous fertilizer on yield and on nitrogen percentage would be inversely related, i.e. when the fertilizer

produces a large increase of yield it causes only a small increase, or a depression, on nitrogen percentage, and vice versa. The results of the Institute of Brewing experiments give some evidence that this is so, but the relation is not sufficiently close to reach the level of statistical significance. The regression coefficient of the effect on the nitrogen percentage in the grain of 1 cwt. of sulphate of ammonia per acre on the increment of grain yield in cwt. per acre was $-0{\cdot}0083 \pm 0{\cdot}0049$.

The somewhat complicated relationships which have been discussed in the preceding sections may be summarized as follows:

Supply of nitrogen in the soil	*Nitrogen percentage in grain*	*Effect of nitrogenous fertilizer*
Low	Low	Increment of yield large Nitrogen percentage in grain little affected or depressed
High	High	Increment of yield small Nitrogen percentage in grain increased

Effect of Time of Application of the Nitrogenous Fertilizer

In the experiments so far discussed the sulphate of ammonia was given at the time of sowing. There is some evidence that late applications of a nitrogenous fertilizer have a more marked effect on the nitrogen-content of the grain (Table 6).

TABLE 6. *Effect of Top-dressings of 2 cwt. Nitro-chalk per acre on the Nitrogen-content and Yield of Barley Grain, Rothamsted, 1928*

	No top-dressing	*Top-dressing applied on*			*Standard error*
		May 22	*June 4*	*June 19*	
Nitrogen as per cent. of dry matter	2·09	2·10	2·11	2·16	±0·026
Yield of grain, cwt. per acre .	15·5	15·4	16·5	15·7	±0·61

Date of sowing: March 28.

Only the latest top-dressing on June 19 caused a significant increase in the percentage of nitrogen in the grain, but there is evidence of a steady increase with later applications of the fertilizer. The grain yield was not significantly affected by any of the treatments.

The high nitrogen-content of barley grain grown in moist soils of high organic-matter content, such as the fen soils, may in part be caused by the plant receiving a later supply of nitrogen derived from long-continued nitrification in the soil, which acts like a late top-dressing of nitrogenous fertilizer.

Phosphatic and Potassic Fertilizers

It is frequently stated that phosphatic and potassic fertilizers tend to lower the nitrogen-content of barley grain, but the Rothamsted experiments afford no clear evidence of this. On Hoosfield, lack of phosphate has had no appreciable effect on nitrogen-content, except possibly on

the nitrate-of-soda series of plots, although it has greatly depressed the yield of grain (Table 7). There is no evidence of any effect of potash on percentage of nitrogen in the grain.

TABLE 7. *Percentage of Nitrogen in Barley Grain and Yield of Grain in cwt. per acre. Hoosfield. Average for years 1893–1928**

	No phosphate or potash	*Phosphate*	*Potash†*	*Phosphate and potash†*
No nitrogenous fertilizer				
Nitrogen, per cent.	1·47	1·46	1·47	1·51
Yield	5·2	8·3	5·4	7·9
Sulphate of ammonia				
Nitrogen, per cent.	1·67	1·65	1·64	1·54
Yield	9·3	14·4	10·1	17·4
Nitrate of soda				
Nitrogen, per cent.	1·68	1·56	1·68	1·57
Yield	11·0	18·6	10·8	17·6

* Except 1912, when the field was fallowed.
† Actually 'alkali salts'—sulphates of potash, soda, and magnesia.

In the experiments of the Institute of Brewing series on crops grown in rotation, the average effect of the superphosphate dressing on the nitrogen percentage in the grain in 51 experiments during the years 1922–6 was $-0{\cdot}003 \pm 0{\cdot}011$, which is far from significant.

Superphosphate had no effect on nitrogen-content even at the Norfolk centres, where it considerably increased the yield:

Norfolk Centres. Average 1922–4

	Nitrogen in grain, per cent.	*Yield of grain cwt. per acre*
Superphosphate	1·65	19·2
No superphosphate	1·67	16·1

The effect of the potassic fertilizer was apparently somewhat greater, $-0{\cdot}020 \pm 0{\cdot}012$, but this also was not significant. There was no evidence that the effect of the potassic fertilizer varied with the level of nitrogen-content, for the regression coefficient of the effect of potash on nitrogen percentage on the mean nitrogen percentage, $0{\cdot}010 \pm 0{\cdot}052$, was not significant.

Effect of the Accompanying Seeds Crop on the Nitrogen-Content of Barley Grain

The nitrogen-content of the grain is only slightly affected by the seeds ley usually undersown in it (Table 8).

The depression of nitrogen percentage caused by undersown rye-grass in 1936 was the only significant effect, but a similar result was found in 1931. In both years, clover sown alone tended to increase the nitrogen percentage, but not significantly. These opposite effects of clover and rye-grass are readily intelligible: rye-grass takes up nitrate

from the soil and so reduces the supply available for the barley, whilst clover adds to the nitrogen supply.

TABLE 8. *Effect of Undersowing on the Nitrogen-content of Barley Grain. Nitrogen as percentage of Dry Matter. Rothamsted*

Year	Not undersown	Undersown with			S.E.
		Clover	Rye-grass	Clover and rye-grass	
1931	1·71	1·72	1·69	1·69	..
1936	1·70	1·71	1·68	1·66	±0·016

A similar slight increase in nitrogen percentage occurs in the barley grown in rotation on Agdell field, Rothamsted, part of which is undersown with clover and part is not (Table 9).

TABLE 9. *Nitrogen Percentage of Barley Grain. Agdell field. 12 crops at 4-year intervals between 1853 and 1897*

Treatment of preceding crop	Minerals only				Minerals and nitrogenous fertilizer			
	Roots fed		Roots carted		Roots fed		Roots carted	
	No clover	Undersown with clover	No clover	Undersown with clover	No clover	Undersown with clover	No clover	Undersown with clover
Nitrogen, per cent.	1·26	1·36	1·22	1·26	1·41	1·47	1·31	1·37

This result, however, could also be attributed to residues of the preceding clover crop ploughed in three years before, and in itself is not clear evidence of effects of undersowing.

Effect of Date of Sowing

Late sowing shortens the period of growth and therefore reduces the yield: it also increases the nitrogen percentage in the grain, showing that the nitrogen-uptake by the plant is less reduced than the yield. This effect is seen in all the experiments. Significant regressions of nitrogen-content on sowing date were obtained, not only in the long-continued Rothamsted and Woburn field experiments, but also in the rotation experiments of the Institute of Brewing series at the various outside centres (Table 10).

A delay of 20 days in sowing has caused an addition of about 0·1 per cent. to the nitrogen-content of the grain.

Curiously enough, however, a nitrogenous fertilizer given to late-sown barley produced no greater increase in nitrogen-content of the grain than when given to early-sown barley, in spite of its smaller effectiveness in increasing dry-matter production (Table 11). This shows that a smaller fraction of the nitrogen applied was taken up by the late-sown crop than by the early-sown. Superphosphate had no obvious effect on the nitrogen-content of either the early- or late-sown barley.

TABLE 10. *Relation between Nitrogen-Content of Barley Grain and Sowing-date* [6]

	Mean nitrogen per cent.	*Mean date of sowing*	*Regression coefficient of nitrogen percentage on sowing-date in days*
Barley grown continuously—Hoosfield, Rothamsted (1893–1928)†*			
Unmanured, 1–O	1·47	March 21	0·0052±0·0018
Sulphate of ammonia only, 1–A	1·68		0·0026±0·0021
Complete minerals, no nitrogen, 4–O	1·51		0·0049±0·0019
Complete minerals and sulphate of ammonia, 4–A	1·54		0·0039±0·0018
Farmyard manure, 7–2	1·85		0·0048±0·0018
Stackyard field, Woburn (1887–1926)			
Mean of 6 plots	1·84	April 1	0·0067±0·0024
Barley grown in rotation			
Institute of Brewing Experiments, all centres, 1922–6	1·61	April 1	0·0049±0·0018

* The regression coefficients for the Hoosfield data are partial regressions after the elimination of trend and the effect of varying April–June rainfall, and of yield. All the regressions are significant except that for Hoosfield, plot 1–A.

† Excluding 1912 (fallow) and 1913.

TABLE 11. *Effect of Sulphate of Ammonia and Superphosphate on the Nitrogen Percentage of the Grain of Early- and Late-Sown Barley. Rothamsted, 1932, Plumage Archer*

Nitrogen as per cent. of Dry Matter

	No nitrogen		*Sulphate of ammonia**	
Date of sowing	*March 4*	*April 6*	*March 4*	*April 6*
No phosphate	1·70	1·81	1·68	1·90
Superphosphate†	1·67	1·82	1·70	1·84

* 0·2 cwt. N. per acre. † 0·5 cwt. P_2O_5 per acre.

Effect of Fallowing

Though fallowing has consistently caused large increases of yield on the continuous plots at Rothamsted and Woburn, its effect on the nitrogen percentage in the grain appears to be somewhat variable (Table 12). After the 1912 fallow on Hoosfield and the two-year fallow of 1927 and 1928 on Stackyard field, the nitrogen percentage was depressed below the average for the preceding five-year period, subsequently rising again in the second year after fallow. At Woburn, the comparisons are not strictly valid, for no fertilizers were applied after the fallow, but the depression occurred on the unmanured plot as well as on those which received fertilizers before the fallow, so that it was probably independent of the fertilizer treatment.

After the 1933 fallow on Hoosfield, however, the nitrogen percentage

was slightly increased above the average for the preceding four years, although this was already high because the barley was sown in widely spaced rows to facilitate cleaning operations. In the second year after fallow, the values were distinctly lower than in the previous year, confirming that the immediate effect of fallow was to increase the nitrogen percentage.

TABLE 12. *Effect of Fallowing on the Nitrogen Percentage and Yield of Barley Grain*

	Nitrogen, per cent.			*Yield, cwt. per acre*		
	Unmanured	*Complete artificials*	*Farmyard manure*	*Unmanured*	*Complete artificials*	*Farmyard manure*
Hoosfield, Rothamsted plots	*1–O*	*4–A*	*7–2*	*1–O*	*4–A*	*7–2*
1912 Fallow						
Before fallow, 5-year mean, 1907–11	1·45	1·47	1·84	4·9	19·2	22·5
After fallow, 1st year, 1913	1·34	1·44	1·70	10·8	31·6	32·4
After fallow, 2nd year, 1914	1·45	1·63	1·69	5·8	17·2	20·9
1933 Fallow						
Before fallow, 5-year mean, 1924–8	1·39	1·49	1·74	2·8	11·0	13·5
Before fallow, 4-year mean, 1929–32*	1·91	1·80	2·03	3·8	15·9	18·4
After fallow, 1st year, 1934	2·06	1·94	2·18	15·2	33·5	34·2
After fallow, 2nd year, 1935	1·59	1·51	2·14	5·2	31·0	33·9
Stackyard field, Woburn plots	*1 and 7*	*6*	*11b*	*1 and 7*	*6*	*11b*
1927 and 1928 Fallow						
Before fallow, 5-year mean, 1922–6	1·76	1·88	1·90‡	2·5	5·9	5·5
After fallow, 1st year, 1929†	1·37	1·28	1·32	9·4	14·4	16·9
After fallow, 2nd year, 1930†	1·46	1·38	1·39	5·6	7·8	9·5

* Rows widely spaced.
† No manures applied in these years. ‡ 4 years only, 1923–6.

The difference in effect of fallowing on nitrogen-content in 1913 and 1934 indicates a higher nitrate-content of the soil in the latter than in the former year. This is also shown by the fact that the nitrogenous fertilizer was much more effective in increasing yield in 1913 than in 1934 [3]. The rainfall during the winter of 1912–13 was considerably higher than that of the winter of 1933–4, and the leaching of nitrate from the soil was presumably correspondingly greater.

Effect of Place in the Rotation

The influence of the place of barley in the rotation on its nitrogen-content is related to the various effects described above. Any treatment that delays sowing tends to lower the yield and to raise the nitrogen-content of the barley. Sheep-folding may have this effect, especially when the excretions from the sheep leave the soil rich in nitrogen (Table 13). Where, however, the barley can be sown in time, the preceding crop has far more influence on the yield than on the nitrogen-content: the nitrogen-content data for the barleys examined at the Rothamsted Barley Conference have shown no clear relation to the preceding crop. (See also p. 214.)

Effect of Wide-spacing of the Drill Rows

E. S. Beaven [4] has pointed out that barley sown in widely spaced rows is richer in nitrogen than barley sown in narrow spacing.

TABLE 13. *Effect of Treatment of the Preceding Root Crop on Nitrogen-Content of Barley Grain, Sprowston, Norfolk, 1927*

		Sulphate of ammonia per acre		
	No manure	*½ cwt.*	*1 cwt.*	*1½ cwt.*
Roots folded by sheep .	1·53	1·45	1·46	..
Roots carted, not folded .	1·38	1·29	1·29	1·30

This may account for the high nitrogen percentage obtained in the Hoosfield experiments, when wide spacing was adopted for the purpose of weed eradication in 1929–32 (Table 14).

TABLE 14. *Effect of Wide Spacing of the Rows on the Nitrogen Percentage of Barley Grain. Hoosfield, Rothamsted*

Year	*Mean 1893–1928*	*1929*	*1930*	*1931*	*1932*	*Mean 1929–32*
Spacing of drill rows .	*6 in.*	*24 in.*	*18 in.*	*18 in.*	*18 in.*	
Plot						
Unmanured, 1–O . .	1·47	1·75	2·16	1·76	1·86	1·91
Sulphate of ammonia and complete minerals, 4–A	1·54	1·78	1·70	1·79	1·94	1·80
Farmyard manure, 7–2 .	1·83	1·92	1·90	2·13	2·18	2·03

Although the nitrogen-content can be raised by widening the drills, an experiment at Sprowston [5] suggests that it cannot be lowered by setting them closer than usual, or by increasing the seed rate:

	Close spacing (3½ in.)	*Ordinary spacing (7 in.)*	*Rate of seeding*	
			2½ bu.	*4 bu.*
Average, 3 years, 1928–30 Nitrogen, per cent. . .	1·41	1·38	1·39	1·41

Nitrogen-content of Grain and Deterioration of Yield on the Continuously-cropped Plots

The deterioration of yield that has occurred on some of the plots on Hoosfield and at Woburn has not been accompanied by any marked progressive change in the nitrogen-content of the grain (Table 15).

TABLE 15. *Ten-year Averages of Nitrogen Percentage of Barley Grain, Hoosfield, Rothamsted, and Stackyard Field, Woburn. (Plot receiving complete artificials, N as nitrate of soda)*

	1877–86	*1887–96*	*1897–1906*	*1907–16*	*1917–26*
Hoosfield, Plot 4AA					
Yield, cwt. per acre . .	21·8	19·1	18·6	20·7*	14·8
Nitrogen, per cent. . .	1·54	1·64	1·64	1·49*	1·45
Stackyard field, Plot 6					
Yield, cwt. per acre . .	24·6†	19·2	17·0	9·5	7·7
Nitrogen, per cent. . .	1·73†	1·86	1·86	1·82	1·85

* 9 years only, 1912 fallow. † 1883–6 only.

Effect of Season on the Nitrogen-content of the Grain

Rainfall.—Late spring and early summer rainfall depresses the nitrogen percentage in the grain. Earlier or later in the season rainfall has no demonstrable effect. A detailed examination of the results for Stackyard field, Woburn, gave no indication that differences in manurial treatment influenced the rainfall effect, and the average curve for seven plots is shown in Fig. 3. The greatest depression of nitrogen percentage was produced by rainfall in early June; at this time an inch of rain above the average caused a reduction of nearly 0·15 per cent. Rainfall in March and in August had a slight tendency to raise the nitrogen-content, but these effects were very small and not definitely established.

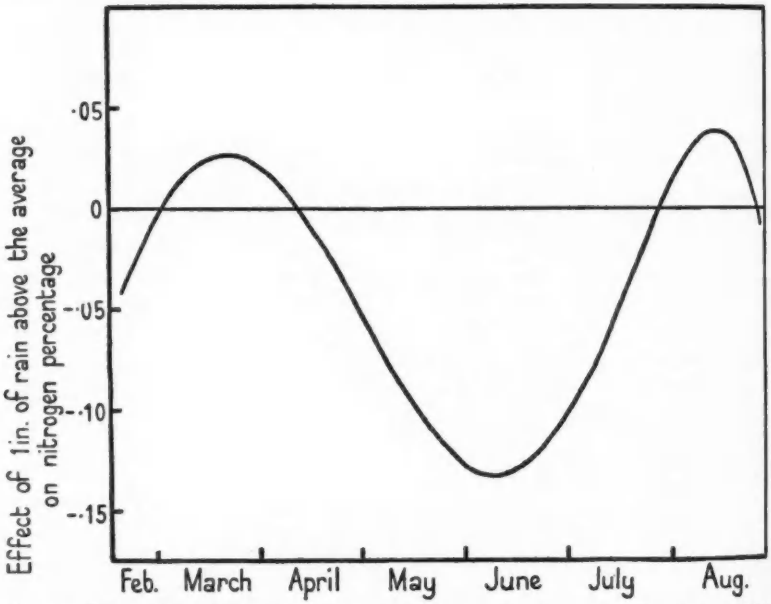

FIG. 3. Effect of rainfall on percentage of nitrogen in the grain. Stackyard field, Woburn. (Mean of seven plots.)

The Hoosfield data have not yet been fully analysed for rainfall effects; a preliminary examination [6] was made by grouping the years according to the amount of rain falling in the three-monthly periods October–December, January–March, and April–June (Table 16). No clear connexion was revealed between nitrogen percentage in the grain and rain falling between October and March, but rainfall in late spring depressed the nitrogen percentage, as at Woburn.

The regression coefficients of nitrogen percentage on April–June rainfall (Table 17) were negative for all the plots examined, but were significant only for the two plots 1–A and 4–A. The magnitude of the

depression of nitrogen percentage per inch of rain was distinctly smaller than at Woburn. On the farmyard-manure plot, 7–2, it was negligible.

TABLE 16. *Mean Nitrogen Percentage for Low, Medium, and High Rainfall Groups. Hoosfield, Rothamsted, 1893–1928* [6]

Plot	1–O	1–A	4–O	4–A	7–2
		(*a*) *October–December Rainfall*			
Below 7·5 in.	1·44	1·64	1·43	1·55	1·84
7·5–10 in.	1·48	1·69	1·57	1·57	1·84
Above 10 in.	1·49	1·67	1·51	1·49	1·86
		(*b*) *January–March Rainfall*			
Below 5·5 in.	1·48	1·69	1·50	1·50	1·88
5·5–7·5 in.	1·49	1·65	1·52	1·57	1·86
Above 7·5 in.	1·44	1·65	1·50	1·56	1·79
		(*c*) *April–June Rainfall*			
Below 5·5 in.	1·57	1·83	1·64	1·67	1·87
5·5–7 in.	1·41	1·58	1·44	1·49	1·86
Above 7 in.	1·42	1·56	1·42	1·44	1·79

TABLE 17. *Effect of April–June Rainfall on the Nitrogen Percentage of the Grain. Hoosfield, Rothamsted, 1893–1928* [6]

	Plot	Mean nitrogen per cent.	Mean April–June rainfall, in.	Regression coefficient* of nitrogen percentage on April–June rainfall
Unmanured	1–O	1·47	6·01	−0·0265 ±0·0149
Sulphate of ammonia only	1–A	1·68		−0·0477† ±0·0178
Complete minerals	4–O	1·51		−0·0304 ±0·0157
Minerals and sulphate of ammonia	4–A	1·54		−0·0393† ±0·0144
Farmyard manure	7–2	1·85		−0·0002 ±0·0148

* Partial regressions after eliminating trend and the effect of varying sowing-date and yield. † Significant.

Comparing the results of Tables 4, 10, and 17, it appears that on the Hoosfield plots receiving no organic manure an additional inch of rain above the average falling in the period April–June lowers the nitrogen-content of the grain by 0·036; a delay of one day in sowing raises it by 0·0042; and an increase in yield of 1 cwt. per acre caused by conditions other than nitrogenous manuring lowers the nitrogen-content by 0·23. On the Woburn plots the rainfall effect is nearly double that at Rothamsted, but the effect of sowing-date is about the same as at Rothamsted.

The effect of late spring rainfall is sufficiently marked to be distinguishable in the short series of Institute of Brewing experiments on barley grown in rotation (Table 18). Here also the depression of nitrogen percentage was greater at Woburn than at Rothamsted, and Wellingore was intermediate.

Temperature.—The results from Stackyard field, Woburn, indicate an apparent dependence of nitrogen percentage in the grain on variations in temperature, but it is not certain whether this is independent of the rainfall effects. Fig. 4 shows the effect of 10° F. of maximum temperature

TABLE 18. *Effect of Rainfall in May and June on the Nitrogen Percentage in the Grain. Institute of Brewing Experiments, 1922–30*

Centre	*Mean nitrogen percentage*	*Mean rainfall in May and June in.*	*Regression coefficient of nitrogen percentage on May–June rainfall*
Rothamsted . .	1·62	4·05	−0·0301 ±0·0442
Woburn . . .	1·67	3·84	−0·1095* ±0·0357
Wellingore . .	1·48	3·39	−0·0616* ±0·0235

* Significant.

above the average on nitrogen percentage in the period February to August for three groups of plots. All agree in showing that high temperatures in June and July increase the nitrogen percentage. The maximum effect was found in July, and it was somewhat greater on plots 3 and 6, which received nitrate of soda, than on plots 1, 4, and 7, which had no nitrogenous fertilizer, or the farmyard-manure plot, 11b. Plots 3 and 6 also differ from the others in that, for these, high temperatures in early spring appear to depress the nitrogen-content.

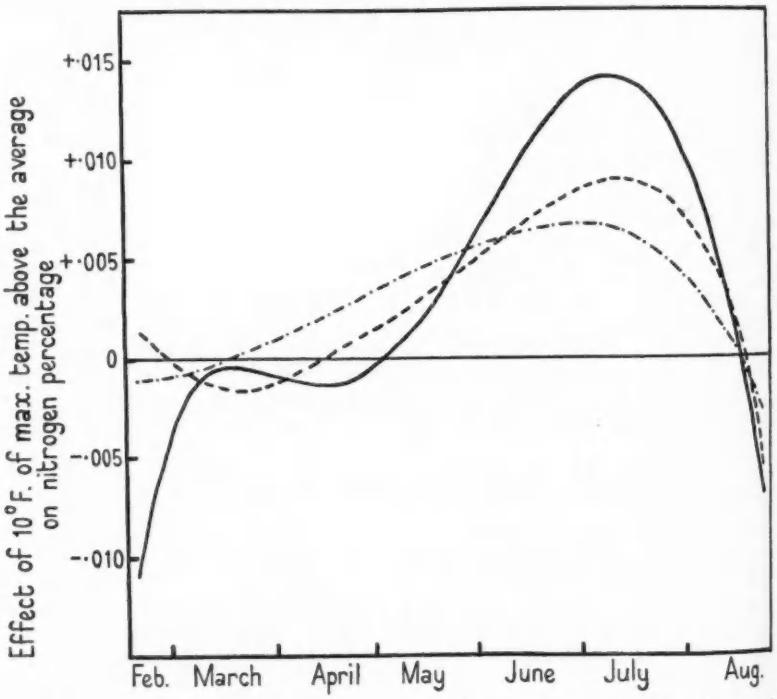

FIG. 4. Effect of temperature on percentage of nitrogen in the grain. Stackyard field, Woburn.

Full line: Mean of plots 3 and 6; nitrate of soda. Broken line: Mean of plots 1, 4 and 7; no nitrogen. Dot-dash line: Plot 11b; farmyard manure.

Phosphorus-content of Barley

On Hoosfield the P_2O_5-content of the grain (Table 19) is markedly lower on the plots receiving no phosphatic fertilizer than on those where it is supplied; there is, however, no evidence of a decline as exhaustion proceeded. This suggests that the amount of P_2O_5 in the grain grown without phosphate has already reached a minimum and any further shortage of assimilated phosphate simply curtails growth and grain-formation.

TABLE 19. *P_2O_5-content of Barley Grain and Straw. Hoosfield, Rothamsted*

	No phosphate given				*Superphosphate supplied*			
	Early years (1868–73)		*Late years (1906–11)*		*Early years (1868–73)*		*Late years (1906–11)*	
	No alkali salts	*Alkali salts*	*No alkali salts*	*Alkali salts*	*No alkali salts*	*Alkali salts*	*No alkali salts*	*Alkali salts*
	Plot 1	*Plot 3*	*Plot 1*	*Plot 3*	*Plot 2*	*Plot 4*	*Plot 2*	*Plot 4*
P_2O_5 in grain (per cent. of dry matter)								
Nitrate of soda (Series AA) .	0·692	0·697	0·635	0·633	0·839	0·863	0·887	0·869
Nitrate of soda + sodium silicate (Series AAS) . .	0·762	0·767	0·715	0·725	0·893	0·927	0·899	0·911
P_2O_5 in straw (per cent. of dry matter)								
Nitrate of soda (Series AA) .	0·084	0·078	0·098	0·101	0·134	0·146	0·208	0·199
Nitrate of soda + sodium silicate (Series AAS) . .	0·093	0·089	0·116	0·114	0·149	0·182	0·235	0·213

The average yields of plots 2AA and 4AA for the two periods was approximately 20 cwt. of grain per acre, and the weight of P_2O_5 contained in the crop in lb. per acre was: in grain, 19; in straw, 5; total, 24; i.e. approximately 80 per cent. of the P_2O_5 is in the grain and 20 per cent. is in the straw.

The addition of sodium silicate has increased the phosphate-content of both grain and straw. Fisher [7] has argued from this result that the silicate exerts its effect on the growth of the crop by increasing the availability to the plant of phosphate in the soil.

These marked effects of phosphatic fertilizer on the P_2O_5-content of the barley grain are, however, not seen in ordinary practice. In the field experiments made on the barley-growing farms the phosphorus-content of the barley grain showed but little variation from season to season or from soil to soil, and was hardly affected by manuring: it was slightly lowered by nitrogenous fertilizers, presumably because they increased the yield, but practically unaffected by phosphatic and potassic fertilizers (Table 20). The usual range was from 0·9 to 1·0 per cent. P_2O_5, and the extreme values were 0·74 to 1·18 per cent.

The winter barleys were somewhat richer in P_2O_5 and poorer in nitrogen than the spring barleys. Among the spring barleys, however, there was no relation between nitrogen-content and P_2O_5-content of the grain.

TABLE 20. *Percentage of P_2O_5 in Dry Matter of Barley Grain* [8]. *Institute of Brewing Experiments, Six centres, 1922–5*

Effect of Fertilizers. Mean of all Experiments

Treatment	*Unmanured*	*Nitrogen phosphate and potash*	*Nitrogen and phosphate*	*Nitrogen and potash*	*Phosphate and potash*
Mean . . .	0·969	0·954	0·948	0·948	0·970
Range . . .	0·74–1·16	0·78–1·18	0·77–1·14	0·77–1·15	0·80–1·15
Nitrogen, per cent. .	1·646	1·620	1·627	1·606	1·586

Seasonal Effects. Mean of all Centres and Fertilizer treatments

	1922	*1923*	*1924*	*1925*	*Mean*
Average . . .	0·968	0·994	0·975	0·909	0·962

Variation between Soils. Mean of all Years and Fertilizer treatments

Rothamsted	*Wellingore*	*Woburn*	*Eyton*	*Orwell Park*
0·965	0·979	0·973	0·897	0·995

Effect of Time of Sowing. N.I.A.B. Variety Trials, Norfolk, 1927

Percentage in dry matter	P_2O_5	N
Spring-sown barleys . .	0·936	1·353
Autumn-sown barleys .	1·008	1·304

Weight of 1,000 Corns[1]

The weight of 1,000 corns depends chiefly on the season: in the Institute of Brewing series it varied from 35–6 gm. in 1926 to 41–2 gm. in 1922, but only slight differences were found between the different soils in similar climatic conditions (Table 21). The effect of fertilizers was negligible.

TABLE 21. *Effect of Soils and Fertilizers on 1,000-corn Weight. Average 1922–6*

Soil type	*1,000-corn weight gm.*	*Fertilizer treatment*	*1,000-corn weight gm.*
Clay . . .	40·3	No manure	39·4
Loam . .	39·8	Sulphate of ammonia and superphosphate	39·7
Sand . . .	38·5	Sulphate of ammonia and potash	39·6
Fen . . .	40·6	Sulphate of ammonia, superphosphate, and potash	39·7
Chalk . .	39·9	Potash and phosphate only	39·9
Mean . .	39·7	Mean	39·7

[1] E. A. Fisher and P. Halton [9] show that this measurement may be subject to large errors unless an adequate and valid method of sampling is adopted.

Effect of season.—The effect of the usually recorded meteorological conditions on 1,000-corn weight appears to be small, and the particular weather factors responsible for the seasonal variation have not been fully identified. At Woburn [10] rainfall above the average in January, February, and March tends to depress the 1,000-corn weight, the most important month being February. No relation can be traced with rainfall in other months. Temperatures above the average in March and April tend to increase the 1,000-corn weight, but it is not known whether this effect is independent of rainfall. It is very remarkable that the 1,000-corn weight appears to have no relation to weather conditions during the time of grain-formation and ripening.

Relation to nitrogen-content.—There is no consistent relation between nitrogen-content and 1,000-corn weight for different samples even of the same variety. If from a particular sample the grains are sorted out according to size, the larger ones usually contain more nitrogen, but this does not hold when different samples are compared.

Specific Gravity of Barley Grain

Numerous determinations of specific gravity of the samples of grain from many of the experiments have been made to see whether the specific gravity is related to other properties. No relation, however, could be discovered, and the variations in specific gravity were small.

The values ranged from 1·25 to 1·3, but when care was taken to remove all air from under the glumes, by repeated exhaustion, slightly higher values, from 1·3 to 1·32, were found.

Weight per Bushel

The weight per bushel of grain has been determined throughout the continuous experiments at Rothamsted and Woburn (Table 22), but not in the Institute of Brewing series or more recent experiments. The mean value for Hoosfield is about 53 lb. per bushel, and for Stackyard field, Woburn, about 52 lb. The weights have changed very little with time, and there is no evidence of any drift associated with the deterioration of yield, even on the acid plots 2A and 5A at Woburn, where the yield has fallen to a very low level. Fertilizer treatments have caused little variation in bushel-weight; a complete artificial fertilizer dressing or farmyard manure appears to give slightly higher values than minerals or a nitrogenous fertilizer alone.

Assuming a bushel-weight of 53 lb. and a specific gravity of the grain of 1·3, with the degree of close packing attained by the usual shaking in the process of filling the bushel-measure, the volume of air-space works out to be 49 per cent., and of solid barley 51 per cent.

When the bushel-weight falls below 53 lb. the sample is not usually good for malting, but from 54 lb. upwards the weight has little relation to malting value; high and low quality can both be found associated with high bushel-weight.

In recent years the bushel has been standardized on a weight basis, for convenience, at 56 lb. for barley.

TABLE 22. *Barley grown continuously. Weight per Bushel of Grain in lb. Ten-year means*

Hoosfield, Rothamsted *Treatment and plot number*	*1852–61*	*1862–71*	*1872–81*	*1882–91*	*1892–1901*	*1902–11*	*1913*–22*	*1923–8†*	*Mean*
Unmanured . . . 1O	51·6	53·1	51·6	52·0	52·6	53·1	53·0	49·3	52·2
Complete minerals, no nitrogen 4O	52·3	54·6	52·6	52·8	53·8	54·4	53·8	49·8	53·2
Sulphate of ammonia only 1A	51·2	53·0	52·0	51·9	52·2	53·5	52·0	49·4	52·0
Nitrate of soda only . . 1AA	..	53·8‡	51·6	52·5	52·4	53·8	52·6	49·7	52·4
Sulphate of ammonia and minerals 4A	52·2	55·8	54·4	53·9	54·2	55·5	54·4	50·8	54·0
Nitrate of soda and minerals 4AA	..	56·6‡	54·3	53·6	54·2	55·4	53·7	50·4	54·0
Farmyard manure . . 7–2	52·6	56·0	54·2	54·3	55·0	56·0	55·1	51·0	54·4

Stackyard field, Woburn	*1877–86*	*1887–96*	*1897–1906*	*1907–16*	*1917–26*	*Mean*
Unmanured . . 1 and 7	51·4	51·2	52·4	50·2	50·2	51·1
Complete minerals, no nitrogen 4A	51·7	51·6	53·2	50·4	50·4	51·5
Sulphate of ammonia only . 2A	52·0	51·8	53·0 (8)	52·5 (4)	51·4 (5)	52·1 (37)
Nitrate of soda only . . 3A	51·7	51·2	51·8	50·4	50·3	51·1
Sulphate of ammonia and minerals 5A	53·2	53·0	53·1	52·4 (6)	51·2 (7)	52·7 (43)
Nitrate of soda and minerals 6	53·0	52·5	53·5	50·6	49·8	51·9
Farmyard manure . . 11b	53·2	53·0	53·8	51·6	51·4	52·6

* 1912 fallow. † Six-year period. ‡ Four years, 1868–71.
The figures in brackets for the Woburn plots 2A and 5A denote the number of years averaged, certain years having been omitted owing to lack of crop.

The Factors concerned in the Production of Malting Barley

Some 40 to 50 per cent. of the barley grown in Britain is malted, so that it is very important for farmers to know what are the conditions favourable to high malting quality.

In their first paper, Lawes and Gilbert [11] spoke of high quality as synonymous with high maturation, and they took as its measures the proportion of grain to total produce, the proportion of dressed corn to total corn, and the weight per bushel of dressed corn; they further observed that 'high maturation and low percentages of nitrogen are generally, with the average of our seasons, coincident . . . the percentages of nitrogen can be but little increased beyond the perhaps abnormally low amount obtained when the nitrogen supply was obviously in defect without at the same time a diminution in the practically admitted characters of high quality of the corn'.

J. M. H. Munro and E. S. Beaven [12] carried the problem a good deal farther, and pointed out that the maltster requires a well-matured barley which will germinate well and 'modify' well, i.e. the cell walls of the endosperm must easily break down so as to liberate the starch and allow its subsequent hydrolysis by the diastase. The malting process does not consist in the production of sugar, but in the liberation of starch so that sugar may be produced in the process of brewing. Well-matured grain has external characteristics which a practised eye can at once detect, and on these most malting barley is bought. A cross-section of the grain further shows that it has a 'mealy' appearance, as distinguished from the 'steely' look of ill-matured grain: a small hand-implement is used

for cutting the grain. In addition, however, the brewer wants a high content of starch, i.e. a high proportion of endosperm, and a low proportion of certain nitrogenous compounds which lead to difficulties in the making or keeping of beer.

The requirements are obviously very complex, and it is not surprising that no chemical method has been devised for completely measuring 'quality'. In spite of much research, quality still eludes precise definition and measurement.

As already pointed out, the nitrogen compounds are related quantitatively to each other for any given variety, and consequently the percentage of any particular nitrogenous compound is related to the percentage of total nitrogen. Further, a low proportion of nitrogen compounds obviously means a higher proportion of non-nitrogenous compounds, i.e. of the fermentable carbohydrates. Low nitrogen-content, therefore, gives the maltster two of his three groups of requirements: high yield of extract, and low content of objectionable nitrogen compounds, but it is not a complete index of quality because it affords no indication of the state of maturation.

For the present we can give no better description of 'malting quality' than to say that the barley should be fully matured, of low, but not too low, nitrogen-content, and of moderately high 1,000-corn weight.

Maturation is a question of season and of soil: the farmer's only control is to sow early: but not too early, for if the young plant is badly checked it may yield a poor sample. Early sowing has the further advantage of affording the safest method known of avoiding gout fly [13].

The standard width of drilling (about 6 inches) is probably the best. Barley grown in wider rows may contain a higher percentage of nitrogen in the grain.

Nitrogen-content of the grain is the best single guide to malting quality, and it is significant to note that wherever a number of samples are examined the grades assigned by the valuers solely on inspection are almost invariably in the order of the average nitrogen-content. Where, however, differences in soil conditions have led to marked differences in colour and maturation, the relation of valuation and nitrogen-content is broken: the average results of the large-scale Institute of Brewing experiments are given in Table 23. The chalk soils produced the barley of lowest nitrogen-content, but the samples did not appeal to the valuers as much as those grown on the loams. The fen samples were much disliked. Apart from these, however, the order of valuation is the inverse of the order for nitrogen-content. Maltsters are insistent, however, that barleys of very low nitrogen-content are not particularly desirable: the optimum value seems to range between about 1·35 and 1·5 per cent.

The nitrogen-content of the grain is easily raised but not easily lowered. It is raised by late sowing and by supplying too much nitrogen in the manure: contrary to earlier hopes, it is not much lowered by phosphatic and potassic fertilizers. It tends to be higher after roots fed off by sheep than after wheat or barley, and to be raised slightly by the clover commonly sown in it. But this fear need not prevent the use of nitrogenous fertilizers in moderate quantity: dressings of sulphate of

ammonia or nitrate of soda supplying about 20 lb. of nitrogen per acre are unlikely to raise the nitrogen-content appreciably unless it is already above about 1·6. This is illustrated by Table 24.

TABLE 23. *Relation of Valuation of Barley Grain to Nitrogen-Content and 1,000-Corn Weight*

Nature of soil	*Nitrogen, per cent. of grain. Average of all experiments*	*1,000-corn weight, gm.*	*Valuation (Loam = 100)*
Chalk	1·46	39·9	96·1
Light and medium loam .	1·53	39·8	100
Heavy loam . . .	1·62	40·3	91·4
Fen	1·73	40·6	80·1
Light sand . . .	1·78	38·5	89·5

TABLE 24. *Effect of Fertilizers on Nitrogen Percentage, 1,000-Corn Weight, Valuation, and Yield of Barley Grain. Average of all Experiments, Institute of Brewing Series, 1922–5*

		No nitrogen	*Nitrogen (20 lb. per acre) as sulphate of ammonia*		
	No fertilizer	*Potash and phosphate only*	*+phosphate*	*+potash*	*+phosphate and potash*
Nitrogen, per cent. in grain . . .	1·59	1·57	1·63	1·61	1·60
1,000-corn weight, gm..	..	39·6	39·1	39·2	39·3
Valuation in shillings per quarter . .	52·3	53·1	53·3	53·8	53·5
Yield, cwt. per acre .	16·8	17·4	20·0	19·6	20·1

Modern stiff-strawed varieties will stand up to a good deal of nitrogen if sown early, and so long as this is done there is no need to hesitate about taking barley after a well-manured crop such as sugar-beet. The results of the Rothamsted Barley Conferences accord with the general preference for a corn crop as the best preparation for high-quality barley, but some of the best barleys sent to the Rothamsted Conferences have followed sugar-beet. Of all preparations the best appears to be a dead fallow, but good results have been obtained from a bastard fallow; one of the worst preparations is a late-fed root crop that necessitates late sowing.

Nitrogenous fertilizer can be given, and on some soils superphosphate also, but potassic fertilizers are less needed. A chloride (e.g. sodium or ammonium chloride) has in a number of trials proved advantageous. Broadly speaking the aim should be a good well-grown crop. So long as the crop stands up well, the heavier the yield the more likely is the quality to be good: but if the crop is laid the quality is likely to suffer considerably through uneven maturation.

The Rothamsted Conferences have shown that many samples of barley

are spoiled at harvest time by premature cutting and gathering,[1] faulty management in the stack, and bad threshing. These, and the right choice of tilth and of sowing-date, are the chief difficulties of the barley-grower.

Barley is rather intolerant of soil acidity, and at Woburn it failed completely on plots of pH 4·5, though it grew well when the pH was above 5·3.

The practical conclusion is that malting quality is dependent chiefly on soil and seasonal conditions. Farms normally producing good malting barley will continue to give equally good samples with enhanced yields, as the result of using fertilizer, especially nitrogenous, but farms which do not usually produce malting barley cannot be made to do so by any scheme of manurial treatment so far tried. We cannot specify any treatment which would give regularly from a light sand, a heavy loam, or a fen, a low-nitrogen barley such as is normally obtained from the light or medium loam. Early sowing and the use of a stiff-strawed variety represent the only direct steps that can be taken to lower the nitrogen-content. Artificial fertilizers applied with the seed do not detract from the prospects of a malting sample, but a dry spring may do so completely.

Of the agricultural problems still to be solved perhaps the most important is to find some way of overcoming the various bad effects of the late sowing which may be forced upon a farmer by unfavourable spring weather.

The Growth of the Barley Crop: Summary

We can now bring together the results recorded in the preceding pages and build up from them a picture of the growing crop. We shall confine ourselves to growth in the field: the wider range of conditions obtainable in pot experiments has been discussed by F. G. Gregory [14].

The young plants synthesize carbohydrate material in their leaves, and assimilate from the soil nitrate, phosphate, potassium, and other salts, in amounts dependent on the quantities available in the soil. Of these the phosphate and potassium appear to have but a narrow range of action; after a certain minimum amount is exceeded, further supplies seem almost without effect either on yield or composition of the plant. Beyond this minimum the uptake of phosphate varies little with the soil supply: the uptake of potassium extends over a wider range, and the uptake of nitrogen over a still wider range.

An increase in the supply of nitrogen to the plant causes an increase in leaf-area, brought about partly by the production of more shoots and thus more leaves, and partly by an increase in the area of individual leaves.

In consequence, production of carbohydrate is increased. There is, of course, no constant proportionality between the amount of nitrogen taken up and the amount of assimilation, but under normal conditions of growth 50 or 60 parts of dry organic matter are synthesized for one

[1] Prior to the introduction of the binder it was usual to leave barley out for several days after it was cut, and to turn the swath by hand so that each side might take the dews.

part of nitrogen taken up. Some 25 to 50 per cent. of the nitrogen of the added fertilizer may be assimilated: the lower level was attained on the barley-growing farms, the higher on the continuous barley plots at Rothamsted and Woburn.

The effect of nitrogenous fertilizers in increasing the number of tillers is shown by the results of counts made in the Rothamsted experiments (Table 25). The differences do not become appreciable until the end of May. Superphosphate also may cause a small increase in the number of shoots per plant (Table 26).

TABLE 25. *Effect of Nitrogenous Fertilizer on Shoot-number. Rothamsted*

Mean Number of Shoots per Metre-length of Drill-row

Date	*No nitrogen*	*0·2 cwt. N per acre*	*0·4 cwt. N per acre*	*Mean*	*S.E.*
1927,* May 3 . .	40·7	42·0	45·1	42·6	1·81
May 31 . .	72·7	94·8	108·6	92·1	3·24
July 28 . .	99·8	123·2	141·0	121·3	9·43
1928,† May 7 . .	41·9	48·9	43·1	44·6	0·95
May 30 . .	75·6	101·9	105·4	96·7	6·18

* Great Harpenden field. See *Rothamsted Annual Report*, 1927–8, p. 131.
† Long Hoos field. See *Rothamsted Annual Report*, 1927–8, p. 133.

Mean Number of Shoots per Plant

Date	*No nitrogen*	*0·2 cwt. N per acre*	*0·4 cwt. N per acre*
1927, May 3 . .	1·46	1·37	1·34
May 31 . .	2·61	3·09	3·23
1928, May 7 . .	1·13	1·20	1·15
May 30 . .	2·65	3·27	3·36

TABLE 26. *Effect of Superphosphate on Shoot-number*

Mean Number of Shoots per Plant

Date	*No phosphate*	*Phosphate*
1927, May 3 . .	1·42	1·35
May 31 .	2·90	3·08

Meanwhile the number of plants per acre is steadily diminishing (Table 27). In one of the Rothamsted experiments the number of seeds sown per metre-row was about 60: by the end of April the number of

TABLE 27. *Number of Plants per Metre of Drill-row*

Date	*Seeds sown (approximate estimate)*	*Plants surviving*			*Mean*	*S.E.*
		No nitrogen	*0·2 cwt. N per acre*	*0·4 cwt. N per acre*		
1927, May 19	60	27·5	30·7	33·6	30·7	1·53
1928, April 27	60	40·1	40·9	43·9	41·6	1·44
May 7	..	37·2	40·9	37·5	38·4	2·08
May 30	..	28·5	31·2	31·4	30·6	1·58

plants was about 40, but this fell to 30 by the end of May. The fall was less where nitrogen was supplied. There were no significant differences as between the various nitrogenous fertilizers.[1] Phosphate has less, if any, effect in increasing the survival rate.

Towards the end of June or in early July, the ears emerge from their ensheathing leaves, and rapid growth of the grain follows. The nitrogen-content, as percentage of dry matter of the grain, varies little during its development, tending to fall slightly at first and subsequently rising again [15].

The approximate constancy of nitrogen percentage indicates that carbohydrate and nitrogen compounds enter the grain at the same relative rates throughout the growth of the grain; this is contrary to the old belief that most of the nitrogen passes into the grain in the early stages and the carbohydrate follows later. It might be assumed from this result that the grain grows at the expense of reserve material existing in the leaves and stem before ear-emergence, carbohydrate and nitrogen compounds moving into the grain at constant relative rates dependent on the relative amounts of these substances present in the reserves. This, however, is not the true explanation, for though there is very little uptake of nitrogen by the plant after ear-emergence, so that all the nitrogen which passes to the ear is derived from existing reserves in the shoot, most if not all of the carbohydrate which enters the grain is formed after ear-emergence, and a considerable fraction of it, up to 30 per cent., is produced by photosynthesis in the ear itself [16]. The approximate constancy of nitrogen percentage in the grain throughout its development appears to be the result of a balance between the rates at which carbohydrates and nitrogen are supplied to the ear, associated with the normal conditions of growth in the field. If the carbohydrate supply is restricted by shading the ear or the shoot after ear-emergence, so that photosynthesis in these parts is prevented, the total amount of nitrogen which enters the ear is very little affected, though the dry weight of the ear is considerably reduced, and consequently the nitrogen percentage is much increased [16].

At harvest, in normal conditions, 70 to 75 per cent. of the nitrogen

[1] Except that in one year a heavy dressing (0·4 cwt. N per acre) of cyanamide reduced the number of plants:

Number of Plants per Metre of Drill-row

Date	*No nitrogen*	*Sulphate of ammonia*	*Cyanamide*	*Urea*	*Muriate of ammonia*	*Mean*	*S.E.*
1927, May 19: (0·2 cwt. N per acre . .	27·9	31·1	31·5	29·7	30·2	30·7	3·06
(0·4 cwt. N per acre) . .	..	33·4	25·8	32·5	42·7	..	..
1928, April 27 .	40·1	42·2	42·6	..	..	41·6	1·44
May 7 .	37·2	37·2	40·9	..	..	38·4	2·08
May 30 .	28·5	31·8	33·2	..	28·9	30·5	1·93
1929, April 19 .	..	40·6	39·0	..	..	39·8	4·12
1930, May 31 .	12·2	..	13·7	..	..	12·9	1·14

in the above-ground parts of the plant, and 40 to 50 per cent. of the dry matter, is contained in the grain.

In the later stages of growth some of the potassium in the plant, and to a less extent the phosphate, is returned to the soil through the root, and part may be washed out by the action of rain and dew, but there is no clear evidence of a similar loss of nitrogen.

Not all the shoots, however, form ears; some of them die, and part of the material in them passes back to the rest of the plant; others remain small and form small ears of small grain. Usually about half of them form normal ears: the proportion varies with the conditions and increases with increasing nitrogen supply (Table 28). Superphosphate also tends to increase the number of ears (Table 29).

TABLE 28. *Effect of Nitrogenous Fertilizers on Ear-number*

Mean Number of Ears per Metre of Drill-row

Year	No nitrogen	0·2 cwt. N per acre					0·4 cwt. N per acre						
		Sulphate of ammonia	Muriate of ammonia	Cyanamide	Urea	Mean	Sulphate of ammonia	Muriate of ammonia	Cyanamide	Urea	Nitrate of soda	Mean	S.E.
1927	32·0	50·3	51·2	..	..	50·8	60·7	67·9	..	..	..	64·3	..
1928	43·6	57·0	60·8	58·1	60·5	59·1	62·7	63·7	59·3	59·0	..	61·2	2·99
1930	45·9	..	..	..	..	..	46·7	50·9	48·4	..	46·0	48·0	1·94
Number of Ears as percentage of Shoots at the end of May													
1927	44·0	53·2	53·9	..	..	53·6	57·6	59·1	..	..	..	58·4	..
1928	57·7	56·4	64·1	52·9	..	57·8	62·7	65·3	50·0	..	..	59·3	..

TABLE 29. *Effect of superphosphate on Ear-number*

Mean Number of Ears per Metre of Drill-row

Year	No phosphate	Phosphate
1927	47·7	50·4
1928	53·7	55·5

The number of ears per unit area of crop depends more on the amount of nitrogen available than on the number of plants, so that, within wide limits, the yield is independent of the number of plants per unit area finally attained. A low plant-number is compensated by an increase in the number of ears formed per plant, or in the size of the ear. In 1930, for example, the number of plants was only about 30 per cent. of that in 1927 and 1928, but the number of ears was about 80 per cent. and the yield per acre was actually higher (Table 30).

Nitrogenous fertilizers may also increase the yield by increasing the number of grains per ear (Table 31, 1930 experiment), but this effect is smaller and probably less regular in its occurrence than the effect on ear-number.

It has already been shown (p. 210) that the size of the grain, as measured by 1,000-corn weight, is unaffected by fertilizers.

TABLE 30. *Relation of Plant and Ear-number to Yield*

Numbers per Metre of Drill-row

Year	*Plants in May*	*Ears at harvest*	*Yields of grain cwt. per acre*
1927	30·7	56·9	16·6
1928	30·6	61·1	16·6
1930	12·9	47·6	23·3

TABLE 31. *Effect of Nitrogenous Fertilizer on Mean Number of Grains per Ear (Rothamsted)*

Year	*No nitrogen*	*0·2 cwt. N per acre*	*0·4 cwt. N per acre*	*S.E.*
1927	29·3	28·7	27·8	..
1928	..	23·6	23·4	1·17
1930	25·8	..	27·1	0·34

In Table 32 the effect of nitrogenous fertilizer on the three growth-attributes, ear-number, number of grains per ear, and size of grain, which together determine the yield of grain, are brought together for comparison.

TABLE 32. *Analysis of the Effect of Nitrogenous Fertilizers on Grain Yield. Increase due to Nitrogen Application, as percentage of 'No Nitrogen' Value*

	1927		*1928*		*1929*
	0·2 cwt. N per acre	*0·4 cwt. N per acre*	*0·2 cwt. N per acre*	*0·4 cwt. N per acre*	*0·4 cwt. N per acre*
Increase in:					
Number of ears per metre of drill-row	58·8	100·9	35·5	40·4	4·6
Number of grains per ear	−2·0	−5·3	..	..	5·0
Weight per grain (1,000 corn weight)	1·4	−1·1	−0·5	−1·6	0·7
Yield	47·5	74·6	21·0	27·3	17·2

TABLE 33. *Attributes of the Barley Crop. Average Data*

Approximate figures per acre		*Composition*				
			Per cent.		*Cwt. per acre*	
			Grain	*Straw*	*Grain*	*Straw*
Seed rate	1·25 cwt.	Dry matter	85	85	15	19
Number of seeds	1·5 millions	*Percentage in dry matter*			*lb. per acre*	
Number of plants at end of May	0·75 millions	N	1·6	0·6	32	14
Ears	1·5 millions	P_2O_5	0·9	0·15	18	4
Grains per ear	25	K_2O	0·6	1·0	12	20
Yield	Grain 18 cwt. Straw 22 cwt. Total 40 cwt.					

in the above-ground parts of the plant, and 40 to 50 per cent. of the dry matter, is contained in the grain.

In the later stages of growth some of the potassium in the plant, and to a less extent the phosphate, is returned to the soil through the root, and part may be washed out by the action of rain and dew, but there is no clear evidence of a similar loss of nitrogen.

Not all the shoots, however, form ears; some of them die, and part of the material in them passes back to the rest of the plant; others remain small and form small ears of small grain. Usually about half of them form normal ears: the proportion varies with the conditions and increases with increasing nitrogen supply (Table 28). Superphosphate also tends to increase the number of ears (Table 29).

TABLE 28. *Effect of Nitrogenous Fertilizers on Ear-number*

Mean Number of Ears per Metre of Drill-row

Year	No nitrogen	0·2 cwt. N per acre					0·4 cwt. N per acre						
		Sulphate of ammonia	Muriate of ammonia	Cyanamide	Urea	Mean	Sulphate of ammonia	Muriate of ammonia	Cyanamide	Urea	Nitrate of soda	Mean	S.E.
1927	32·0	50·3	51·2	..	..	50·8	60·7	67·9	..	..	..	64·3	..
1928	43·6	57·0	60·8	58·1	60·5	59·1	62·7	63·7	59·3	59·0	..	61·2	2·99
1930	45·9	..	..	..	..	..	46·7	50·9	48·4	..	46·0	48·0	1·94
Number of Ears as percentage of Shoots at the end of May													
1927	44·0	53·2	53·9	..	..	53·6	57·6	59·1	..	..	..	58·4	..
1928	57·7	56·4	64·1	52·9	..	57·8	62·7	65·3	50·0	..	..	59·3	..

TABLE 29. *Effect of superphosphate on Ear-number*

Mean Number of Ears per Metre of Drill-row

Year	No phosphate	Phosphate
1927	47·7	50·4
1928	53·7	55·5

The number of ears per unit area of crop depends more on the amount of nitrogen available than on the number of plants, so that, within wide limits, the yield is independent of the number of plants per unit area finally attained. A low plant-number is compensated by an increase in the number of ears formed per plant, or in the size of the ear. In 1930, for example, the number of plants was only about 30 per cent. of that in 1927 and 1928, but the number of ears was about 80 per cent. and the yield per acre was actually higher (Table 30).

Nitrogenous fertilizers may also increase the yield by increasing the number of grains per ear (Table 31, 1930 experiment), but this effect is smaller and probably less regular in its occurrence than the effect on ear-number.

It has already been shown (p. 210) that the size of the grain, as measured by 1,000-corn weight, is unaffected by fertilizers.

TABLE 30. *Relation of Plant and Ear-number to Yield*

Numbers per Metre of Drill-row

Year	*Plants in May*	*Ears at harvest*	*Yields of grain cwt. per acre*
1927	30·7	56·9	16·6
1928	30·6	61·1	16·6
1930	12·9	47·6	23·3

TABLE 31. *Effect of Nitrogenous Fertilizer on Mean Number of Grains per Ear (Rothamsted)*

Year	*No nitrogen*	*0·2 cwt. N per acre*	*0·4 cwt. N per acre*	*S.E.*
1927	29·3	28·7	27·8	..
1928	..	23·6	23·4	1·17
1930	25·8	..	27·1	0·34

In Table 32 the effect of nitrogenous fertilizer on the three growth-attributes, ear-number, number of grains per ear, and size of grain, which together determine the yield of grain, are brought together for comparison.

TABLE 32. *Analysis of the Effect of Nitrogenous Fertilizers on Grain Yield. Increase due to Nitrogen Application, as percentage of 'No Nitrogen' Value*

	1927		*1928*		*1929*
	0·2 cwt. N per acre	*0·4 cwt. N per acre*	*0·2 cwt. N per acre*	*0·4 cwt. N per acre*	*0·4 cwt. N per acre*
Increase in:					
Number of ears per metre of drill-row .	58·8	100·9	35·5	40·4	4·6
Number of grains per ear . . .	−2·0	−5·3	..	..	5·0
Weight per grain (1,000 corn weight) . .	1·4	−1·1	−0·5	−1·6	0·7
Yield . . .	47·5	74·6	21·0	27·3	17·2

TABLE 33. *Attributes of the Barley Crop. Average Data*

Approximate figures per acre		*Composition*				
			Per cent.		*Cwt. per acre*	
			Grain	*Straw*	*Grain*	*Straw*
Seed rate . .	1·25 cwt.	Dry matter	85	85	15	19
Number of seeds .	1·5 millions	*Percentage in dry matter*			*lb. per acre*	
Number of plants at end of May .	0·75 millions					
Ears . . .	1·5 millions					
Grains per ear .	25					
Yield . . .	Grain 18 cwt.	N	1·6	0·6	32	14
	Straw 22 cwt.	P_2O_5	0·9	0·15	18	4
	Total 40 cwt.	K_2O	0·6	1·0	12	20

It is clear that in the 1927 and 1928 experiments the increased yield of grain was produced entirely by an increase in the number of ears per unit area of crop, but in 1930 the effect on ear-number was much smaller, and it was reinforced by an increase in the number of grains per ear. This difference in behaviour is possibly related to the very low plant-number in 1930 (Table 30).

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MANURIAL REQUIREMENTS OF SOILS IN PALESTINE

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Soils.—The soils of arid and semi-arid countries are generally assumed to be deficient in nitrogen, but rich in soluble salts and lime. The summary given in Table 1 shows the amount of exchangeable bases present in typical Palestinian soils. Apart from the red sandy soils of the coastal plain, they are all rich in lime. Small amounts of potash are present, but the percentage of sodium is a much higher one.

TABLE 1. *Exchangeable Bases in Typical Palestinian Soils* (*mg. equivalents per 100 gm. soil*)

	Ca	*Mg*	*K*	*Na*
Red sandy soils	2·5	0·9	0·3	2·6
Terra rossa	58·5	1·1	1·4	4·4
Mediterranean steppe soils	11·3	5·4	0·7	8·6
Lisan marls	58·8	1·2	2·0	4·0
Alluvial soils	33·0	0·7	0·4	3·6

Some experiments tend to show that Palestinian soils do not as a rule respond so much to potash fertilizers as to nitrogenous and phosphatic fertilizers [1]. Such practical experience may hold good to a certain extent in some cases, but it would be disastrous if applied to citrus orchards [2, 3], which provide the main cash-crop of the country. The chief centre of citrus culture is situated in the coastal plain, where the soil is mostly formed by a red loamy sand, extremely deficient not only in nitrogen and phosphoric acid, but also in potash and lime. The data in Table 2 bear out this contention.

TABLE 2. *Nutrients in and pH Values of Typical Palestinian Soils* (*average figures of several samples*)

	Available nutrients according to Neubauer		*N*	$CaCO_3$	
	P_2O_5	K_2O	(*per cent.*)	(*per cent.*)	*pH*
Red sandy soils	0·0	0·0	0·04	Tr.	7·2
Terra rossa	5·2	38·3	0·12	9·50	7·6
Mediterranean steppe soils	Tr.	26·9	0·01	23·72	8·1
Lisan marls	4·5	14·8	0·07	58·11	7·6
Alluvial soils	0·1	6·1	0·07	12·70	7·9
Loess soils	8·5	25·2	0·07	26·50	7·9

Thus only the terra rossa soils contain a moderate amount of nitrogen, and, apart from the loess, all soils are deficient in phosphoric acid. Most soils contain a fair amount of available potash, exceptions being the alluvial and red sandy soils. The latter soils are also extremely deficient

in lime. The lack of nutrients in the red sandy soils was also proved by the results of pot experiments not yet published.

Manuring.—Only the citrus plantations receive artificial fertilizers on a large scale. All other agricultural soils do not as a rule receive any, and are therefore exhausted, which explains the extraordinarily low yields generally obtained on them. The average yield per hectare is about 480 kg. (3·8 cwt. per acre) in the case of wheat and 630 kg. (5 cwt. per acre) in the case of barley. (In many instances, of course, lack of water is the limiting factor.) The value of chemical fertilizers imported into Palestine has increased fourfold since 1931, and was about £130,000 in 1937. Since only citrus plantations (30,000 ha. in 1938) are systematically fertilized, the remainder of the agricultural land (about 800,000 ha.) suffers continuous impoverishment.

Phosphoric acid.—Double superphosphate is mostly applied in the plantations at the rate of about 500 gm. per tree. Experiments carried out with finely ground local raw phosphate proved to be a failure because of the neutral or slightly alkaline reaction of the soil. There may be a possibility of converting the Transjordan raw phosphates into superphosphate in the future, as they contain about 80 per cent. of tricalcium phosphate [4]. Palestinian raw phosphates contain only about 50 per cent. of tricalcium phosphate, the remainder being calcium carbonate, so that they cannot profitably be converted into superphosphate. It may, however, be possible to increase the phosphoric-acid content by igniting the material and washing out the quicklime formed. Although it was found that such a treatment raised the content of tricalcium phosphate up to 80–85 per cent., there is no proof as yet of its economic feasibility.

Potash.—Potassium chloride is produced from the Dead Sea; in 1937 over 29,000 tons, and in the first 10 months of 1938 some 37,000 tons, were exported. This fertilizer is, however, not used in Palestine, imported potassium sulphate being used instead (at the rate of 300 gm. per citrus tree). This strange state of affairs is due to the fact that the farmer is afraid to increase the chloride-content of the soil, a fear, however, which is baseless, especially so far as the light red sandy soils of citrus groves are concerned. By irrigation alone much more chloride is added to the soil than by manuring with potassium chloride. Assuming the irrigation water to contain only 100 mg. of chlorine per litre, and its amount to be 5,000 cu. m. per hectare, about 500 kg. of chlorine are annually added to one hectare by the irrigation-water alone. By treating one hectare with 150 kg. of potassium chloride, less than 75 kg. of chlorine are added per hectare. Further, injuries observed from the use of irrigation-water containing over 350 mg. of chlorine per litre are not so much to be ascribed to the chlorine-content of the water as to the corresponding amount of sodium, because sodium and not chlorine enters the soil adsorption-complex. Moreover, where good drainage is provided, chlorides do not accumulate in the soil [5]. The sums wasted by the unnecessary application of the much more expensive imported potassium sulphate run into thousands of pounds per annum.

Nitrogen and organic manure.—Nitrogen is applied in the form of

sulphate of ammonia, nitro-chalk, or nitrate of soda, and about 1 kg. of nitrogenous fertilizer is given per tree. All Palestinian soils, including the terra rossa, which contains moderate amounts of nitrogen, respond first and foremost to nitrogen. As the vegetation period is short, a sufficient amount of readily available nitrogen must be present in the soil. A certain economy in the application of nitrogenous fertilizers could be achieved by better preservation of manure, by composting, green-manuring, and the use of town-refuse.

Organic manure is often very badly handled in Palestine, the heaps being exposed not only to the intense sun, but also to the torrential winter rains. The dung is very often left for weeks in small heaps on the field instead of being ploughed in as quickly as possible. On almost all farms the very valuable chicken manure is allowed to dry in the sun, thereby losing most of its easily soluble nitrogen. The following analyses confirm this statement:

TABLE 3. *Analysis of Chicken Manure (percentages calculated on a water-free basis)*

	Ash	*Organic matter*	*N (total)*	*N (easily soluble)*	NH_3–*N*
Fresh manure . . .	57·8	42·2	4·1	3·1	0·9
Sun-dried manure . .	49·6	50·4	2·4	0·8	0·1

These figures, as well as other observations, show the necessity for instructing the agricultural population in regard to the preservation and composting of manure.

The problem of providing sufficient quantities of organic manure of good quality is closely linked up with the nitrogen problem. Although nitrogen can of course be supplied by artificial fertilizers, the use of organic manure for the improvement of soil structure, stimulation of bacterial activity, &c., is most imperative. The easily permeable, red sandy soils in the citrus-belt are deficient in a material that can absorb nutrients and water. Because of the scarcity of organic material in the country, great quantities of manure are imported from neighbouring countries, the price being 20*s.* to 30*s.* per ton. Possibly the low-moor peat found in the north of Palestine (Huleh region) may prove a substitute for organic manure. Our preliminary investigations [5] have shown that an application of 10 tons per hectare of this peat is quite sufficient to absorb all the nutrients added to the soil. The peat contains about 1·0–1·5 per cent. nitrogen, which, although it was without effect in a pot experiment, may become slowly available.

Lime.—As mentioned above, most Palestinian soils are rich in lime, the only exception being the red sandy soils of the coastal plain. On these, liming is absolutely necessary, since every citrus crop removes about 100 kg. CaO per hectare. For example, at the governmental horticultural stations [6], when the pH is under 7, not less than 600 kg. of quicklime (slaked before application) are applied per hectare. A dressing of lime is of course needed not only because of its physiological effect, but also for improving the physico-chemical qualities of the soil.

Fertilizer-balance.—By calculating the quantities of nutrients removed annually from the soil and those added to it in fertilizers a fertilizer balance-sheet is attained. The figures given below have already been published [5], but are reproduced here in a corrected form.

TABLE 4. *Nutrients removed by the Chief Crops of Palestine (1935)*

Crop	*Yield*	*Nitrogen N*	*Phosphates P_2O_5*	*Potash K_2O*
	million kg.	M. tons	M. tons	M. tons
Wheat . . .	104	3,025	1,297	2,161
Barley . . .	68	1,373	687	1,373
Sorghum . . .	46	1,109	512	1,386
Grapes . . .	29	232	87	290
Citrus . . .	[20,000 ha.]	1,260	380	1,470
Totals . . .		6,999	2,963	6,680

Estimated Addition of Nutrients to Palestine Soils (1935)

	Nitrogen N	*Phosphates P_2O_5*	*Potash K_2O*
	M. tons	M. tons	M. tons
Artificial fertilizers (13,000 tons) . .	1,666	1,686	585
Organic manures (150,000 tons) . .	675	300	900
	2,341	1,986	1,485
Deficit	4,658	977	5,195

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THE COMPOSITION OF GRASS AT VARIOUS STAGES OF MATURITY, AND THE CHANGES OCCURRING DURING HAYMAKING, WITH PARTICULAR REFERENCE TO CAROTENE-CONTENT

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ALTHOUGH much experimental work has been carried out since Moore [1] demonstrated the vitamin-A potency of carotene, information on the occurrence of this pigment is still very limited. A preliminary study of the effects of manurial treatment and of age on the carotene-content of grass [2] has now been followed by further experiments, each designed to investigate the influence of particular factors. The results here presented relate to further work on the influence of maturity, carried out during 1938, and to an attempt to correlate the major organic and mineral constituents of grass with its carotene-content.

Experimental

The south-east portion of the Long Riggs meadow at Cockle Park was used for this investigation. The soil is a heavy loam overlying boulder clay, and has the analysis given in Table 1.

TABLE 1. *Analysis of Long Riggs Soil*

	Per cent. of air-dry sample		*Per cent. of air-dry sample*
Coarse sand	13·50	P_2O_5, HCl-soluble	0·198
Fine sand	32·12	K_2O, HCl-soluble	0·339
Silt	14·70	P_2O_5, available	0·035
Clay	24·40	K_2O, available	0·010
Moisture	4·66		
Carbonates	0·03		
Loss by solution	3·13		
Difference	7·46	pH	6·06
	100·00		

Whereas the herbage of the plots on the Roundabouts field, used in the previous investigation [2], contained a very large proportion of Yorkshire fog, the south-east enclosure of Long Riggs was very different, as shown by the results of an analysis made by the percentage-area method on August 26 (Table 2).

This analysis was made after the removal of the hay; the experimental samples were taken prior to cutting. During the investigation much yellow rattle (*Rhinanthus crista-galli*) was observed, but the analysis made showed that there was less than 0·1 per cent. present in August. This inability to recover quickly after cutting is also typical of several other weeds, and in respect of such plants the botanical analysis is certain to be somewhat inaccurate. On the other hand, the figure of 9 per cent. for wild white clover is probably greater than the percentage

occurring under the conditions of growth earlier in the season. With these few exceptions, however, the figures shown in Table 2 agree with field observations made during the experiment, and can be taken as a reliable indication of the nature of the sward.

TABLE 2. *Approximate Herbage Analysis of Experimental Area*

Species	*Per cent.*
Perennial ryegrass (*Lolium perenne*)	27
Sweet vernal (*Anthoxanthum odoratum*)	13
Yorkshire fog (*Holcus lanatus*)	10
Wild white clover (*Trifolium repens*)	9
Crested dogstail (*Cynosurus cristatus*)	8
Cocksfoot (*Dactylis glomerata*)	8
Meadow fescue (*Festuca pratensis*)	7
Meadow foxtail (*Alopecurus pratensis*)	6
Smooth-stalked meadow grass (*Poa pratensis*)	4
Buttercup (*Ranunculus* Sp.)	4
Sorrel (*Rumex* Sp.)	2
Other weeds	2
	100

No fixed plots were used in this investigation, a series of five replicated samples being taken from randomized positions within the experimental area on each occasion, each cut extending over 1 sq. yd. Samples were first taken on April 26, and subsequently at regular fortnightly intervals until July 19; the grass was then very mature and was cut for hay on July 25. To obtain information on changes during haymaking, samples were also taken from the swath on July 25 and 29, and from the 'pikes' on August 4. The height of the grass was noted on each occasion prior to July 25, and the yield from each square yard was weighed and placed in an airtight tin. In the laboratory a sub-sample was drawn from each tin for carotene determination by the method recently described by Moon [3], the remainder being dried for 24 hours at 100° C. The composition of the dried samples was determined by the usual analytical methods.

A severe drought was experienced during April 1938, the rainfall for that month (0·15 in.) being less than one-tenth of the average (1·90 in.). During May and June, however, rainfall was well above normal. Sunshine was below average at all times, but, with the exception of July, was greater than for the corresponding months in 1937; temperatures were somewhat lower than in 1937. Meteorological data for the experimental periods are given in Table 3.

Results

Space does not permit tabulation of full analytical results for all the samples examined, but these may be seen on request. Mean analyses of the samples taken on all occasions during the period April 26–July 19, together with the corresponding standard deviations and differences required for significance, are given in Table 4.

Carotene-content of samples.—The marked fall in carotene-content between April 26 and May 10 synchronized with a period of very low

TABLE 3. *Meteorological Data for Experimental Periods*

Period	Rainfall (inches)	Sunshine (hours)	Temperature		
			Mean grass min. (°F.)	Mean screen max. (°F.)	Mean screen min. (°F.)
April 12–25	0·02	51	34·0	52·3	37·5
April 26–May 9	0·16	107	33·1	53·2	35·5
May 10–23	1·21	47	42·6	55·9	42·7
May 24–June 6	3·96	43	43·0	56·7	44·6
June 7–20	0·46	102	44·1	63·0	46·2
June 21–July 4	0·93	77	45·8	60·9	47·8
July 5–18	1·38	38	45·1	60·9	48·0
July 19–August 1	0·81	75	49·1	65·9	51·1

TABLE 4. *Mean Percentage Values for Organic and Mineral Constituents, and Summary of Analyses of Variance*

	April 26	May 10	May 24	June 7	June 21	July 5	July 19	Standard deviation	z	P	Sign. difference
Mean height (in.)	2·4	3·6	4·8	10·4	11·3	13·7	23·0	..	..	..	..
Dry matter	29·61	31·03	28·61	24·71	23·24	22·64	30·22	..	..	..	..
Carotene (mg. %)	38·16	24·04	22·57	16·52	13·69	10·16	12·13	2·686	2·0868	<0·01	3·92
Crude protein	14·69	11·54	12·73	11·82	10·51	9·39	8·48	0·719	1·8699	<0·01	1·05
True protein	12·22	9·44	10·76	9·74	8·86	8·40	7·99	0·639	1·6330	<0·01	0·93
True/crude protein	0·83	0·82	0·85	0·82	0·84	0·89	0·94	0·022	1·9683	<0·01	0·03
Ether-extract	3·53	2·58	3·03	3·13	2·85	2·74	1·96	0·317	1·2390	<0·01	0·46
Nitrogen-free extract	55·91	56·83	56·56	53·16	52·02	50·84	49·99	1·157	1·6969	<0·01	1·69
Fibre	16·41	18·84	20·36	24·12	27·46	29·22	31·53	1·095	2·4499	<0·01	1·60
Ash	9·45	10·20	7·31	7·77	7·16	7·81	8·05	0·947	0·9803	<0·01	1·38
Silica	3·41	4·61	1·57	2·27	2·59	2·11	2·43	0·715	1·1444	<0·01	1·04
Silica-free ash	6·05	5·59	5·75	5·50	4·57	5·69	5·62	0·665	0·4389	>0·05	..
Lime (CaO)	1·19	1·22	0·97	0·81	0·83	0·79	0·73	0·137	1·1851	<0·01	0·20
Phosphoric acid (P_2O_5)	0·88	0·77	0·80	0·88	0·85	0·71	0·72	0·050	1·1710	<0·01	0·07

rainfall and a daily average of more than 7·5 sunshine hours (Table 3). Although the grass sampled on May 10 was 50 per cent. higher than on April 26, it is very doubtful whether any importance can be attached to this difference; much larger variations have been found between samples taken simultaneously from various parts of the field. As there was little increase in dry matter between April 26 and May 10, which was not surprising considering the weather, the marked fall in carotene-content must be ascribed to the drought. (This conclusion is supported by data relating to samples taken during the same period in connexion with other experimental work not recorded here; in all cases there was a marked fall in carotene-content following the period of very low rainfall.) Although there was a significant and marked loss of carotene, the drought was not so severe as to scorch appreciably the young grass. Atkeson *et al.* [4] have also reported a marked loss of carotene by grass during the hot midsummer months in Kansas, but they give no meteorological data and no information regarding the stage of growth and condition of the plants analysed.

Little further change in carotene-content occurred until the end of May, when meadow foxtail and sweet vernal began to flower. It has been frequently assumed that little loss of carotene occurs prior to flowering, and the work of Virtanen [5] with peas has suggested that carotene-content may increase to a maximum immediately before

flowering. Although the earlier part of this investigation (April 26–May 10) was undoubtedly affected by the unusual weather, and requires to be repeated in a more normal season, the samples taken on May 24 had been grown under comparatively moist conditions, and yet showed no increase in carotene-content when compared with the analyses for May 10. It is possible that the effects of the drought lasted longer than the drought itself, for no indication of increase in carotene-content was observed from May 10, when the grass was only 3·6 in. high, to May 24, when flowering was just starting. In the absence of further evidence, it may be concluded that, for herbage of the type analysed, carotene-content shows no increase during growth from a height of 4 in. to the flowering stage.

By June 7 there were many inflorescences of meadow foxtail, sweet vernal, and several other species, and carotene had fallen to 16·52 mg. per 100 gm. dry matter. Flowering continued throughout June and was completed by July 5, when the mean carotene-content had again shown a significant decline. No further loss occurred during the post-flowering period, July 5–25; on this last date the mean carotene-content was 14·27 mg. per 100 gm. dry matter (see Table 7), the significant increase of 4·11 over the figure for July 5 being probably due to a bottom-growth of young grass, following the increased rainfall. It was noticed on July 19 that although the average height of the main growth was 23 in., there was a somewhat 'drawn' bottom-growth of leafy grass, 12 in. high.

Under the conditions of this experiment the losses of carotene associated with increasing age and height were very similar. Although it may seem that age and height are of equal value as criteria of stage of growth where carotene-content is concerned, it should be borne in mind that at the start of this experiment the effect of the drought was so marked as to mask changes in carotene-content due to any other cause. It seems almost certain that under more normal climatic conditions the early fall in carotene-content will not be nearly so marked.

Yields of dry matter and carotene.—The present experiment was not designed to provide accurate information on yield of dry matter, the analysis of the samples being the most important consideration and plots of a single square yard being used primarily for convenience in sampling. Large errors in yield-data resulted from the use of such small plots, and although the mean dry-matter yields increased regularly from first to last, many of the differences failed to reach the level of significance. There was no significant variation in the yields of carotene.

Organic constituents.—Woodman and co-workers [6] have reported that drought causes a fall in moisture-content and in the amount of protein present in pasture grass; both these effects were noticeable in the present investigation during the dry period (Table 4 and Fig. 1). Recovery from the drought resulted in a significant increase of 10 per cent. in the protein-content (May 24), which subsequently showed the normal and more or less regular decline with advancing maturity; the content of true protein showed essentially the same variations.

In accordance with expectation the ratio of true to crude protein increased regularly and significantly from June 21 to July 19 (Table 4).

During the earlier stages of growth, however, the ratio remained virtually unchanged, except that the grass sampled on May 24 gave a mean figure higher than on May 10 or June 7. As this difference only just attained the level of significance, it seems doubtful whether any great importance can be attached to it.

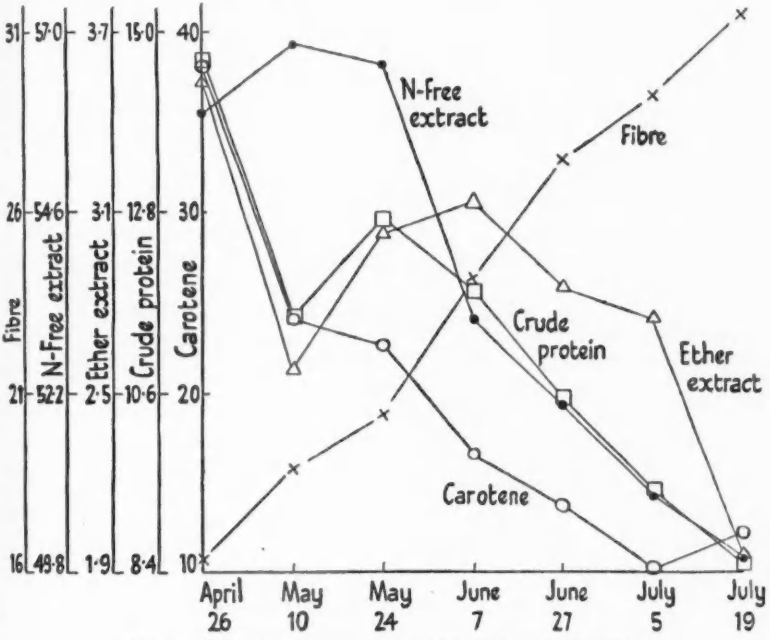

FIG. 1. Variations in carotene and organic constituents.

The ether-soluble fraction of the samples showed a marked fall during the dry period April 26–May 10, which was followed by a less marked, but nevertheless significant, increase in the succeeding fortnight; it then remained more or less constant until July, when a loss of 28 per cent. occurred. Knowledge of the ether-extractives of grass is very limited, but from such information as is available a depression under drought conditions would hardly be expected. Thus Woodman, Norman, and French [6] have indicated that ether-extract is depressed by moist quick-growing conditions, rather than by drought. It may be noted, however, that several analyses of pasture grass have been recorded [7, 8, 9] showing a depression of ether-extract during mid-season, when dry conditions are common and growth is retarded. The marked fall in ether-extract which occurred during July is also without obvious explanation, although similar losses have been observed during the conversion of grass into hay [10, 11], and, as the grass had reached a very advanced stage of maturity when this loss occurred, possibly the same causes operated in the two cases.

The continued decline in nitrogen-free extract from May 24 to July 19 may be ascribed to lignification associated with advancing maturity and the conversion of carbohydrate constituents into 'crude fibre'. Fibre-content rose consistently from first to last, as was to be expected.

Mineral constituents.—The contents of total ash and silica of the samples taken on April 26 and May 10 were significantly higher than for any obtained subsequently, but the high figures obtained were doubtless due to greater soil contamination when the grass was short. If these samples be excepted, no significant variations in ash or silica occurred during the experiment; even when all samples are considered, there is no significant variation in the silica-free ash.

The variations in contents of lime and phosphoric acid are shown graphically in Figure 2. The variation in calcium-content followed that of carotene more closely than did the phosphoric acid. Lime-content showed a marked fall during May and only a relatively slight decrease subsequently. It is generally recognized that the leaves of all pasture plants contain most calcium, and a fall in this constituent may therefore be expected when flowering begins and the proportion of leaf declines. Flowering occurred at the end of May, at the same time as the observed fall in lime-content. Phosphoric acid varied more irregularly, decreasing significantly during the dry period and increasing on the recovery from drought; a further loss occurred at the end of June. Orr [12] has concluded that 'drought has the effect of decreasing the percentage of phosphorus' in pasture, and the results obtained in this experiment point to the same conclusion; it also seems that recovery from drought may lead to a similar recovery in phosphorus-content.

Correlation of Carotene with Organic and Mineral Constituents

Little is known concerning the relationship between content of carotene and the amounts of organic and mineral constituents present in grass; therefore 'complete' analyses were carried out on all samples taken in this investigation. How far the variations in organic and mineral constituents resemble those of carotene can be seen from the occasion means in Table 4 and Figs. 1 and 2. Correlation coefficients for each constituent are given in Table 5, together with the corresponding values of z.

If $P = 0{\cdot}05$ be taken as the level of significance, significant correlations with carotene were obtained for all constituents except silica and silica-free ash. The significant figure obtained for total ash was probably due to soil contamination leading to erroneously high ash-contents in the early samples, and little importance can therefore be attached to it.

The correlations for both true and crude protein were highly significant and positive, a result which agrees with previous observations [2]. The significant negative correlation between carotene and the ratio of true to crude protein recalls Virtanen's conclusion [13] that the carotene-content of plants is closely related to growth, factors that retard growth affecting carotene-content adversely, and optimum growth oc-

curring simultaneously with maximum carotene-content. Virtanen has also concluded that these phenomena indirectly indicate that carotene is an important growth-factor of plants. Since active growth is also characterized by a relatively high proportion of non-protein nitrogen, and therefore a low ratio of true to crude protein, and maturity is associated with both a low carotene-content and a high ratio, a significant negative correlation between carotene and this protein ratio is not

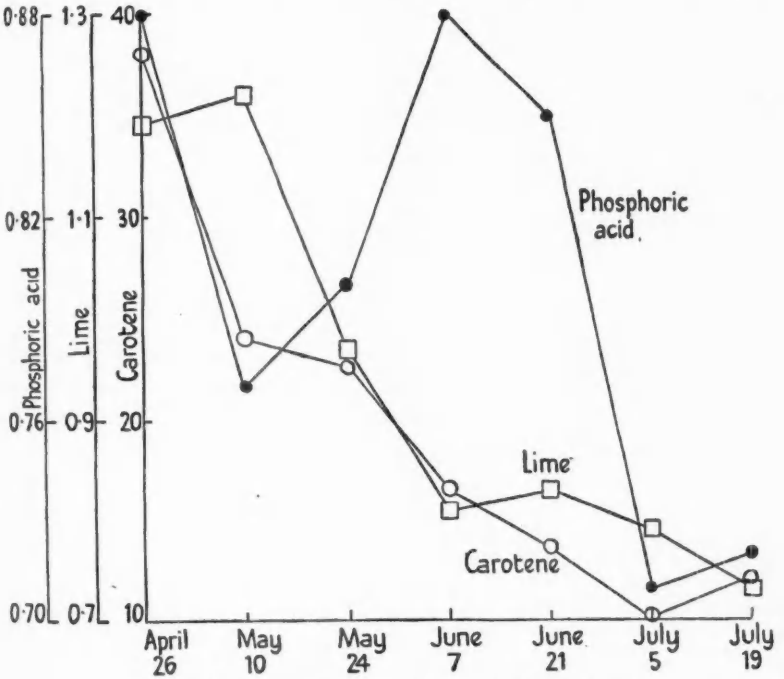

FIG. 2. Variations in carotene, lime, and phosphoric acid.

surprising. The second column in Table 5 shows, however, that the degree of correlation is significantly less than was obtained for either true or crude protein, the difference in the values of z (0·8989) considerably exceeding twice the standard error.

The correlation of ether-extract with carotene is also appreciably less than for protein, although it is highly significant. A similar figure was obtained for nitrogen-free extract.

As had been anticipated, a highly significant negative correlation was obtained for fibre, this correlation being equally as good as that obtained for protein.

The figures for lime and phosphoric acid are both highly significant, but nevertheless significantly lower than the correlation coefficients for protein and fibre.

TABLE 5. *Correlations with Carotene*

Fraction		*r*	*z*
Crude protein		+0·89	+1·4219
True protein		+0·89	+1·4219
True/crude protein		−0·48	−0·5230
Ether-extract		+0·57	+0·6475
Nitrogen-free extract		+0·72	+0·9077
Fibre		−0·88	−1·3757
Ash		+0·42	+0·4477
Silica		+0·29	+0·2986
Silica-free ash		+0·32	+0·3317
Lime		+0·69	+0·8479
Phosphoric acid		+0·41	+0·4357
S.E. of difference of 2 values of *z*		..	0·2500
Significant values of *r*	$P = 0{\cdot}01$	0·43	..
	$P = 0{\cdot}02$	0·39	..
	$P = 0{\cdot}05$	0·33	..

Changes in Composition during Haymaking

The grass was mown for hay on July 25, turned on July 28 and 30, 'coiled' on August 1, and 'piked' on August 2. The daily weather data for this period are given in Table 6. Samples for analysis were taken on July 25, immediately after cutting, and on July 29 and August 4. The mean composition for each occasion and the summarized analyses of variance are shown in Table 7.

TABLE 6. *Meteorological Data, July 25–August 2, 1938*

Date		*Rainfall (inches)*	*Sunshine (hours)*	*Temperature*		
				Mean grass min. (°F.)	*Mean screen max.* (°F.)	*Mean screen min.* (°F.)
July	25	0·44	6·7	44	71	48
	26	0·00	10·0	54	66	48
	27	0·26	8·6	43	67	45
	28	0·01	6·3	53	63	50
	29	0·03	2·2	44	64	48
	30	0·01	0·0	59	69	61
	31	0·00	3·2	52	70	56
August	1	0·00	13·2	41	66	47
	2	0·00	4·9	52	64	52

Carotene-content of samples.—The loss of nearly 50 per cent. of carotene during the period July 25–9 (Table 7) was not unexpected in view of the weather conditions (cf. Table 6). Very heavy rain fell on July 25, immediately after cutting, followed by three relatively sunny days during which the hay was turned in the swath. Greenhill [14] has reported a 22 per cent. loss of carotene in 54 hours for freshly cut grass 'under good but comparatively cool weather conditions in May', and has noted that the outer layers lost colour much more rapidly than the less exposed material. The weather during the experiment under discussion appears to have been much less favourable than it was during Greenhill's experiment, and as the turning on July 28 would undoubtedly have

an adverse effect on carotene-content, it is somewhat surprising that the total loss did not exceed 50 per cent. This may be due to the relatively low initial carotene-content of the freshly cut hay, which was only 14·27 mg. per 100 gm. dry matter, compared with 40 mg. in the young grass which Greenhill had under examination.

The remaining period during which the hay was on the ground (July 29–August 1) was more favourable, there being relatively little sunshine and only 0·04 in. of rain. The loss of carotene during this period was not so great, and together with the loss due to two days in the pike, only just exceeded the value of 3·18 necessary for significance.

TABLE 7. *Mean Percentage Composition of Field-dried Samples and Summary of Analyses of Variance*

	July 25	*July 29*	*Aug. 4*	*Standard deviation*	*z*	*P*	*Sign. difference*
Carotene (mg.)	14·27	7·21	4·00	2·184	1·6826	<0·01	3·18
Crude protein	7·11	7·93	8·00	0·692	0·4697	>0·05	..
True protein	6·42	6·79	7·18	0·580	0·3773	>0·05	..
True/crude protein	0·90	0·86	0·90	0·035	0·4581	>0·05	..
Ether-extract	1·76	1·75	1·77	0·151	−1·9120	<0·05	..
Nitrogen-free extract	52·11	50·21	49·95	0·830	1·1596	<0·01	1·21
Fibre	32·62	32·87	33·64	0·946	0·2282	>0·05	..
Ash	6·35	7·24	6·64	0·374	0·9601	<0·05	0·54
Silica	1·93	2·72	2·66	0·271	1·2888	<0·01	0·39
Silica-free ash	4·46	4·52	3·99	0·339	0·6551	>0·05	..
Lime	0·67	0·66	0·66	0·091	−1·5162	<0·01	..
Phosphoric acid	0·68	0·66	0·61	0·057	0·3233	>0·05	..

Organic and Mineral Constituents.—Of the organic and mineral constituents, the only fractions which showed any significant changes during field drying were nitrogen-free extract, total ash, and silica. Nitrogen-free extract showed a small but significant decline during the early stages of drying (July 25–9), a change which would be expected to occur as a result of respiratory and fermentative action. The percentage of total ash increased significantly from 6·35 on July 25 to 7·24 on July 29, but then declined significantly to 6·64 by August 4. Increases in total ash during the curing of hay have been observed by Watson, Ferguson, and Horton [10], and also by Thomas and Thompson [11]. The latter writers have concluded that such changes indicate losses due to respiration rather than to mechanical causes, since the ash constituents are least affected by respiration. It would thus appear that respiration loss produced a decrease in nitrogen-free extract and an increase in ash during the period July 25–9, whilst the mechanical losses during 'piking' led to a significant decline in ash-content between July 29 and August 4. Silica-content varied in a manner similar to that of total ash, but the decline between July 29 and August 4 failed to reach the level of significance. The variations in silica-free ash were too great to permit the detection of any differences between the three occasion means.

In a similar study on grass from an adjacent field, Thomas and Thompson [11] observed that, in four plots out of five, protein and fibre increased during curing, whilst in every case there was a loss of ether-extract. Although increases in protein and fibre were also observed in

the present investigation they could not be considered significant. As previously stated, ether-extract showed a significant decline immediately prior to cutting for hay, and, as Table 7 shows, no further loss occurred during the conversion into hay. Lime and phosphoric acid also showed no significant variation during curing, a result similar to that obtained by Thomas and Thompson. It is clear that under the conditions of field drying the loss of carotene far exceeds that of any of the organic and mineral constituents studied.

Summary

Carotene-content was depressed by the drought in April 1938; it then remained constant until flowering began, when a marked loss occurred, but did not further decrease during the post-flowering period.

Variations in carotene-content associated with increasing age and height were very similar, but the unusual weather during the early part of the experiment may have affected the result.

Dry-matter yields increased during the flowering period, but there were no large changes in yields of carotene during the experiment.

Variations in content of organic and mineral fractions are discussed, and related to variations in carotene-content. Significant correlations with carotene were obtained for protein (+0·89), nitrogen-free extract (+0·72), and fibre (−0·88). Less close but significant correlations were obtained for ether-extract, ratio of true to crude protein, lime, and phosphoric acid.

A loss of nearly 50 per cent. occurred in the carotene-content of mown grass during four days in the swath, when the weather was very unfavourable. The loss during the following six days, when conditions were more satisfactory, was barely significant.

There were few changes in the quantities of organic and mineral fractions during haymaking, the most important being a small loss of nitrogen-free extract and an increase in total ash, both attributed to respiration. Under the conditions of field drying the loss of carotene far exceeded that of any of the other constituents studied.

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THE CAROTENE-CONTENTS OF SOME GRASS AND CLOVER SPECIES, WITH A NOTE ON PASTURE WEEDS

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THE effects of manurial treatment and of maturity on the carotene-content of grass have been described in previous papers [1, 2]. Whilst botanical composition is probably not without influence on the carotene-content of pasture herbage, such influence would seem to be small under conditions of close grazing or cutting; under a less intensive system of management, however, the species constituting the sward may possibly possess a very great influence on carotene-content. Since pasture plants differ appreciably in the relative amounts of leaf and stem occurring at maturity, differences in carotene-content are much more likely to be noticeable under non-intensive conditions, when a more advanced stage of maturity is attained.

Atkeson, Peterson, and Aldous [3] have reported on the carotene-content of several pasture plants commonly grown in Kansas, and their results indicate that the most important differences resulted from the varying responses of the several species to the local meteorological conditions, which were apparently characterized by a very dry midsummer, followed by autumn rain. No similar information appears to be available for pasture plants grown in Britain. In order to obtain some preliminary data, samples of several species were taken from the Northumberland County Experimental Station at Cockle Park in October 1937. The analyses of these have been discussed elsewhere [4], and it need only be stated here that the most outstanding result was the remarkably high carotene-content of the weeds earthnut (*Conopodium denudatum*) and dock (*Rumex obtusifolius*).

During 1938 samples of 7 grasses and 3 clovers were taken at monthly intervals, in order to examine more thoroughly the differences between species at several periods during the growing-season and at various stages of growth. To obtain information on the carotene-contents of weeds, random samples of 7 weeds were taken at monthly intervals from pasture-land.

Experimental

The grasses and clovers examined in this investigation were obtained from the Lower Nursery at Cockle Park, where they had been cultivated in rows for two years; no weeds were available in the Nursery, so these were obtained from Plot 6 of the Roundabouts pasture. Analyses of the soils on Lower Nursery and Roundabouts are shown in Table 1.

The grasses and clovers were cut back on definite dates, so that the exact age of each sample was known; this was not possible with the weeds obtained from Roundabouts, which were sampled at random within the plot throughout the season. On all occasions the height of each species was noted, and samples cut with scissors were wrapped in

waterproof paper, and transferred to the laboratory in sealed tins. Carotene- and dry-matter contents were determined immediately on the fresh material, the former by the process described by Moon [5], using the Lovibond tintometer and Ferguson's [6] carotene curve, and the latter by drying a portion at 100° C. for 24 hours.

TABLE 1. *Analyses of Lower Nursery and Roundabouts Soils (Per cent. of air-dry samples)*

	Lower Nursery	*Roundabouts*
Coarse sand	21·26	15·20
Fine sand	28·80	36·44
Silt	13·52	14·38
Clay	20·83	22·35
Moisture	9·97	3·11
Carbonates	0·19	0·02
Loss by solution	2·17	1·66
Difference	3·26	6·84
	100·00	100·00
HCl-soluble P_2O_5	0·186	0·178
HCl-soluble K_2O	0·115	0·158
Available P_2O_5	0·015	0·019
Available K_2O	0·019	0·015
pH	6·68	6·23

Meteorological data.—Rainfall, sunshine, and temperature data for the period March–October 1938, together with the mean rainfall and sunshine figures for the corresponding months in the preceding 20 years, are given in Table 2.

TABLE 2. *Meteorological Data*

Month	*Rainfall (in.)*	*Average rainfall for 20 yrs. 1918–37 (in.)*	*Sunshine (hours)*	*Average sunshine for 20 yrs. 1918–37 (hours)*	*Temperature*		
					Mean grass min. (° F.)	*Mean screen max. (° F.)*	*Mean screen min. (° F.)*
March	0·42	1·87	105	105	38·4	53·9	41·8
April	0·15	2·14	134	133	35·1	51·9	37·6
May	3·50	2·22	156	168	39·2	55·5	40·4
June	2·66	1·75	181	183	45·0	61·3	47·0
July	2·67	2·80	118	164	46·7	62·9	49·0
Aug.	4·74	3·00	141	154	48·7	63·5	50·0
Sept.	1·97	2·53	113	129	45·0	61·6	46·7
Oct.	3·41	2·70	103	101	39·0	54·7	41·9

The total rainfall during March and April was exceptionally low, being less than 25 per cent. of average during March and less than 8 per cent. of the average during April. In May, June, and August, however, the total precipitation exceeded the means for the corresponding months during the period 1918–37 by more than 50 per cent. The hours of bright sunshine were more or less normal in all months except July,

when the figure recorded in 1938 was more than 25 per cent. less than the average for that month.

The spring of 1938 was unusually mild and the species cultivated in the Lower Nursery, which has a well-sheltered position, made a good early growth, many of them approaching the flowering-stage before severe drought started in April. All plants were therefore cut close to the ground on April 28 and the summer growth examined in the following months; very rapid growth occurred in May and June, all species again reaching a very advanced stage of maturity. As flowering of the grasses was completed by July 21, it was decided to investigate the carotene-content of leaf-material only on the next occasion (Aug. 15). All grasses and clovers were then cut down for the second time and the autumn growth examined on Sept. 15 and Oct. 13.

Results

Results obtained for the spring, summer, and autumn series of samples are given in the Appendix, the mean carotene-contents for species and for occasions being as shown in Table 3.

TABLE 3. *Summary of Mean Carotene-contents*

Species	*Carotene (mg. per 100 gm. dry matter)*	*Occasion*	*Carotene (mg. per 100 gm. dry matter)*		
			Grasses	*Clovers*	*All samples*
Yorkshire fog (*Holcus lanatus*)	33·71	March 30	57·61	49·23	54·47
Perennial rye-grass (*Lolium perenne*)	25·79	April 28	29·17	49·91	35·39
Italian rye-grass (*Lolium italicum*)	23·69	May 26	25·84	43·46	31·13
Cocksfoot (*Dactylis glomerata*)	28·34	June 23	13·46	32·42	19·15
Timothy (*Phleum pratense*)	30·12	July 21	13·26	32·53	19·04
Meadow fescue (*Festuca pratensis*)	33·63	Aug. 15	15·34	32·85	20·59
Tall oat-grass (*Avena elatior*)	31·18	Sept. 15	39·08	54·73	43·78
Broad red clover (*Trifolium pratense*)	44·29	Oct. 13	43·10	60·72	48·39
Early white clover (*Trifolium repens*)	44·24				
Wild white clover (*Trifolium repens*)	44·91				

The occasion means show that in all months but March the clovers were much richer in carotene than the grasses. Although this may be ascribed to the relatively high leaf-stem ratio in the clovers, it should be noted that even on Aug. 15 the clovers were far superior to the grasses, when the latter were sampled without the flowering stems. It is difficult to account for the marked superiority of the clovers on this

date, although the higher moisture-content of these plants may render them less affected by summer conditions.

All species were very rich in carotene on March 30, when active spring growth was in progress, but a loss of 35 per cent. occurred in the following month. The marked adverse effect of drought conditions on the carotene-content of grass has already been observed [2], and the very noticeable decline shown in Table 3 is almost certainly the result of this cause.

It will be noted that although a mean loss of 35 per cent. occurred between March 30 and April 28, the grass species showed a loss of 48·6 per cent. whilst the carotene-content of the clovers increased slightly. This pronounced difference between the grasses and clovers may be explained if Virtanen's [7] theory of the relationship between carotene and growth be accepted. Thus, if it be assumed that the carotene-content of grass in the dormant state immediately before spring growth is relatively low, and that it increases rapidly as growth begins, then differences between the carotene-contents of grasses and clovers are to be expected in spring. Whereas the grasses and broad red clover had already begun to grow vigorously by March 30, as shown by their high carotene-contents, the early white clover, only 1 in. high and containing relatively little carotene, was just beginning active growth. Wild white clover, with still less carotene, was in a more or less dormant condition. During the period March 30–April 28, the grasses may be considered to have passed their period of maximum growth, and the ensuing fall in carotene-content was hastened by the very bad drought at this period. In the case of the clovers, however, active growth reached a maximum at a later period, so that the effect of the drought in reducing carotene-content would be less marked. The wild white clover was last to start growth, and showed an increase of 37·8 per cent. in carotene-content; the earlier variety showed only 1·6 per cent. increase, whilst broad red clover, which started growth at a still earlier date, showed a decrease of 22·4 per cent.; this last value is still considerably lower than the average for the early-growing grasses.

The summer samples were grown during a period (May–August) when rainfall was somewhat above average, and it is unlikely that the drought experienced during April would have any influence on their carotene-contents. Nevertheless, growth was very rapid during May, and there was a marked fall in carotene-content during the flowering-period May 26–June 23; by this last date, however, the peak of the flowering-period was passed and the loss of carotene between June 23 and July 21 was quite small. Although the samples analysed on July 21 contained a considerable proportion of stem, whilst stemmy material was excluded from the grass samples taken on Aug. 15, carotene-content showed only an insignificant increase between these two occasions; such a result strongly suggests that there was actually a fall in the carotene-content of the leaves.

Since the mean carotene-contents for clovers did not differ between June and August, and were consistently greater than those for grasses, it appears that the carotene-content of clovers may be far less affected by age than that of graminaceous plants.

The high carotene-content during autumn growth (Table 3) is in agreement with preliminary work done in 1937 [1, 4]. It is also evident that the autumn clover samples contained much more carotene than the grasses, although both showed similar increases between September and October.

The means for species in Table 3 show the three clovers to be very similar in carotene-content; with the exception of the two rye-grasses, the species of gramineae examined were also very similar. Differences between the carotene-contents of the three clovers in March and April have already been discussed, and it will be seen from the Appendix that there were no consistent variations during the summer and autumn months. The rye-grasses contained least carotene during the spring, and also in May and June. In July, however, perennial rye-grass was inferior only to the clovers; this grass was the first to start flowering, and it seems from the July results that it was also the first to renew leaf-growth after flowering. Italian rye-grass is usually considered as yielding a leafier hay than the perennial species, but during 1938 it certainly was not richer in carotene. The lower summer carotene-values obtained for Italian rye-grass may be the result of the taller growth of this plant, and possibly a reduced proportion of leaf, although the August leaf samples still showed the perennial rye-grass to be slightly superior. Both rye-grasses were appreciably 'burnt' in autumn, and further declines in carotene-content resulted.

Although the mean carotene-contents of the remaining grasses varied relatively little, several quite marked differences were observed at certain periods during the season. Thus tall oat-grass and meadow fescue were particularly rich in carotene on March 30, and also contained more carotene than any of the other grasses in May and June. Meadow fescue maintained its relative position in July, but tall oat-grass, which had increased in height from 24 in. in June to 44 in. on July 21, lost 38·1 per cent. of its carotene during the same period, and on the latter date was superior only to Italian rye-grass and timothy. Of the August samples, the leaves of tall oat-grass, with an average height of 16 in., contained the least carotene, whereas meadow fescue (11 in. high) proved to be one of the best grasses sampled. These results may be explained to some extent by the morphological and growth characteristics of the plants concerned. Thus Stapledon and Hanley [8] state that meadow fescue is 'a decidedly productive grass which gives rise to a more leafy hay than perennial rye-grass, and also to a more abundant aftermath and a more plentiful summer grazing'. Tall oat-grass, on the other hand, is very different in its growth; although 'it starts active growth in the spring earlier than most other species', if not heavily grazed 'the product rapidly becomes stemmy and unpalatable'. The exceedingly high carotene-content of tall oat-grass on March 30 would seem to be the result of an early active growth, and the rapid decline during the summer months was undoubtedly the result of maturity, stemminess being very pronounced by July. The autumn growth was also somewhat inferior in respect of carotene-content; by October 13 this grass had grown to a height of 14 in. and although there was only a small

amount of stem, there was appreciable 'yellowing' and carotene-content had fallen to 32·20 mg. per 100 gm. dry matter. On the other hand, meadow fescue, which maintained a higher carotene-content than the majority of grasses during the summer, also contained more than the average amount of carotene in September and October.

Cocksfoot and Yorkshire fog were very similar in carotene-content during spring and early summer, but inferior to tall oat-grass and meadow fescue; during July, however, when all species were in flower, little difference was noticeable between these four grasses. Whereas the majority of grasses showed some 'yellowing' in October, Yorkshire fog appeared to be least affected, and on the last sampling occasion contained 61·58 mg. carotene per 100 gm. dry matter, an amount inferior only to that possessed by early white clover. Cocksfoot was somewhat exceptional in showing the lowest carotene-content on Sept. 15, but producing an increase of 50 per cent. between that date and Oct. 13.

Although timothy contained quite a high content of carotene during March and April, this declined more than in any other species during the summer months, being less than that of any other sample on July 21. Like tall oat-grass, this plant made rapid and luxurious growth, reaching a height of 34 in. on the last date mentioned, being then very coarse and containing very little leaf. The 'non-flowering' material sampled on Aug. 15 resembled that of tall oat-grass in many ways, and possessed a similarly low content of carotene. Stapeldon and Hanley [8] state that timothy is 'decidedly winter green', and the autumn samples obtained in this investigation showed no evidence of any loss of carotene due to frost damage; the carotene-content of this grass was 40·79 mg. per 100 gm. dry matter on Sept. 15, and increased a further 9·7 per cent. in the following month.

From the results considered above it seems reasonable to conclude that season, and in particular its effect on stage of maturity, is of far greater influence on the carotene-content of grass than the actual species constituting the herbage. No one species appears to maintain a higher carotene-content than other grasses consistently throughout the season; for limited periods and under certain conditions, differences between species may, however, be quite considerable. If the growth characteristics of any particular grass are known, e.g. earliness or lateness, leafiness or stemminess, it should be possible to estimate fairly accurately the carotene-content for any given period. In plants like the clovers, which do not form nearly so much stem as do most graminaceous plants, the influence of maturity will be far less, and the loss of carotene during the summer months will not be nearly so great.

Carotene-contents of Pasture Weeds

The heights and carotene-contents of seven weeds on six sampling occasions, together with the mean carotene-contents for species and occasions, are shown in Table 4. It is obvious that comparatively little control was possible in the case of the random sampling of weeds from a pasture plot, and this is shown very clearly by the relatively great variations in the heights of individual species. Nevertheless, the samples

obtained can be regarded as being representative of the weed material available for grazing or conserving.

In the preliminary work carried out in 1937 [4], very high carotene-contents were obtained for autumn samples of the weeds earthnut and dock, and it was for this reason that a number of weeds were included in the 1938 investigation. The high carotene-contents on all occasions during 1938 are worthy of note. During the summer months May–August, the mean carotene-contents for weeds were comparable with the means for clovers, and far superior to the corresponding figures for grass samples. The autumn rise in carotene-content occurred earlier in the case of the weeds, starting in August but not continuing after September; with both grasses and clovers this increase was not obtained until September, and continued into October. It should be noted, however, that the grasses and clovers were cut down in August, whereas the weeds were not so treated. Although the autumn carotene-contents of the weeds were not quite so high as those of the clovers, with the exception of thistle, the September samples compared very favourably with the majority of grasses sampled in that month.

TABLE 4. *Heights (inches) and Carotene-contents (mg. per cent. of dry matter) of Pasture Weeds*

	Plantain (Plantago lanceolata)	*Yarrow* (Achillea millefolium)	*Buttercup* (Ranunculus spp.)	*Speedwell* (Veronica chamaedrys)	*Ragwort* (Senecio jacobea)	*Nettle* (Urtica dioica)	*Thistle* (Carduus arvensis)	*Carotene occasion mean*
May 24:								
Height	2·5	1·5	1·3	1·5	2·0	3·0	3·0	
Carotene	40·50	46·58	41·67	34·40	35·74	46·82	36·61	40·33
June 21:								
Height	4·5	4·0	3·5	4·0	7·0	11·0	9·0	
Carotene	43·09	33·25	31·16	34·94	21·44	24·67	32·26	31·54
July 19:								
Height	3·0	2·0	1·5	2·0	2·0	12·0	14·0	
Carotene	32·43	30·84	38·81	28·66	38·23	24·33	31·82	32·16
Aug. 15:								
Height	6·0	3·5	3·0	4·0	4·5	12·0	5·0	
Carotene	43·55	44·35	63·88	39·76	46·91	33·61	39·43	44·50
Sept. 13:								
Height	6·0	3·5	3·0	3·0	10·0	12·0	11·0	
Carotene	48·63	34·49	56·99	43·19	55·47	50·35	24·67	44·83
Oct. 11:								
Height	4·0	3·5	4·0	3·5	4·5	7·0	8·0	
Carotene	35·18	38·13	38·29	32·89	41·76	50·56	31·73	38·36
Mean carotene-content	40·56	37·94	45·13	35·64	39·93	38·39	32·75	

Seasonal variations in carotene-contents were very similar, there being a general tendency for a decline in June or July, and a rise in August or September. In most cases the carotene-content in October was either equal to or less than the corresponding value for September. In general, it appears that the content of leaf-carotene decreases rapidly with the approach of flowering, and rises in the post-flowering period to a high autumn value, before again decreasing when growth terminates. The active growing-season of these plants seems to be shorter than for other pasture herbage; many of the weeds examined showed evidence of dying

off in October, which no doubt accounts for the stationary or declining carotene-contents at this period.

Summary

An examination has been made of the carotene-contents of 7 grasses and 3 clovers at several periods during the growing-season and at various stages of growth.

In the spring, carotene-content appears to be related to growth activity.

The summer carotene-content of grasses depends chiefly on stage of maturity, all grasses being somewhat similar at the flowering-period. Varietal differences in respect of the typical amounts of stemminess or leafiness at any given age may, however, have an appreciable effect. Clovers are usually not nearly so stemmy as the grasses in mid-season, and have higher carotene-contents.

Carotene-content generally increases in autumn, except (*a*) when growth ceases, (*b*) when growth is so rapid as to result in a state of advanced maturity, and (*c*) when there is an appreciable amount of frost damage.

It has been shown that a number of grassland weeds possess relatively high carotene-contents at all periods of the season; during the summer months they are comparable with the clovers and far superior to the grasses.

Although the clovers and weeds are much more reliable sources of carotene than the grasses, showing much less seasonal fluctuation, the length of their growing-season is somewhat restricted. The majority of grasses have a longer period of growth and should therefore be of particular value in the early spring, and also in late autumn if they are 'winter green'.

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APPENDIX

Heights (inches) and Carotene-contents (mg. per cent. of dry matter) of Grass and Clover Species

	Spring samples				*Summer samples*			
	March 30		*April 28*		*May 26*		*June 23*	
	Height	*Carotene*	*Height*	*Carotene*	*Height*	*Carotene*	*Height*	*Carotene*
Yorkshire fog	6·0	60·39	5·0	29·66	5·0	29·02	8·0	14·06
Perennial rye-grass	4·0	43·04	6·5	25·86	7·0	18·41	13·5	9·41
Italian rye-grass	6·0	45·55	6·5	20·90	8·0	18·49	16·5	8·15
Cocksfoot	4·5	59·65	6·5	31·08	8·5	20·26	20·0	13·77
Timothy	4·5	58·20	7·0	33·75	8·0	27·54	20·0	12·84
Meadow fescue	4·5	63·11	6·5	31·37	8·0	31·23	20·0	14·21
Tall oat-grass	7·3	67·04	13·5	31·55	8·5	35·93	24·0	21·75
Broad red clover	3·0	59·40	4·5	46·12	5·5	48·70	9·0	22·78
Early white clover	1·0	49·86	3·3	50·64	3·0	35·14	5·0	34·69
Wild white clover	0·7	38·44	0·7	52·98	2·3	46·54	6·5	39·80

	Summer samples				*Autumn samples*			
	July 21		*August 15**		*September 15*		*October 13*	
	Height	*Carotene*	*Height*	*Carotene*	*Height*	*Carotene*	*Height*	*Carotene*
Yorkshire fog	21·0	13·95	4·0	16·88	4·0	44·16	4·5	61·58
Perennial rye-grass	15·0	14·36	7·5	18·77	4·0	39·85	4·5	36·62
Italian rye-grass	20·0	11·88	8·5	15·45	7·5	34·70	10·0	34·39
Cocksfoot	24·0	14·07	17·0	14·93	6·5	29·15	9·0	43·84
Timothy	34·0	11·04	8·0	12·07	4·0	40·79	5·0	44·73
Meadow fescue	24·0	14·07	11·0	18·64	5·5	48·06	7·0	48·34
Tall oat-grass	44·0	13·46	16·0	10·65	8·0	36·87	14·0	32·20
Broad red clover	18·0	35·62	13·0	40·15	5·0	42·48	8·0	59·08
Early white clover	10·0	34·53	7·0	27·27	2·5	54·77	3·0	67·03
Wild white clover	8·5	27·43	7·0	31·13	3·0	66·93	2·0	56·06

* With the exception of the three clover samples, only leaf-material was examined on this date.

DOES SPROUTING INCREASE THE NUTRITIONAL VALUE OF GRAIN?

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NUMEROUS advantages have been claimed from time to time for the sprouting of grain as a means of improving its nutritive value for live stock. C. Crowther [1] has quoted experiments made in the year 1865 which showed that barley was worth more as a food than the amount of malt and malt-culms that could be made from it. He also noted that the results of this experiment did not exclude the possibility that fresh, undried, germinated seed with shoot and rootlet may possess virtues which may be destroyed in kiln-drying. Such special virtues would, of course, include succulence and some of the accessory food factors or vitamins.

A special feature in the sprouting of grain which has been prominent of late is treatment of the germinating seeds with a nutrient solution of salts. Botanists have, of course, used nutrient solutions for centuries, but the formula for a nutrient solution can form the basis of patent rights and such rights have been acquired by a number of advocates of the method.

Recently the grain most commonly used for germinating or sprouting has been maize, and where other grain was used the results have been disappointing. Two reports already published [2, 3] have dealt with the practical methods of sprouting maize for fodder, and it is therefore unnecessary to give further details of its production. A brief report is here presented of further cattle-feeding and nutrition experiments carried out at the National Institute for Research in Dairying with maize sprouted by similar methods and using the same patent solution as described by Paterson [3].

1. *Sprouted Maize versus Flaked Maize for Dairy Cows*

In this experiment milking cows were used and a comparison was made between a ration containing the sprouted product (6 to 8 lb.) obtained from 3 lb. whole maize grain and the same ration with the sprouted maize replaced by 3 lb. flaked maize. The experiment was divided into three periods: (*a*) a preliminary control period when all cows received the same rations, (*b*) an experimental period when half the cows received sprouted maize and half flaked maize, and (*c*) a final control period when all cows were again fed the same rations as during the preliminary control period.

The first six cows which were available for this experiment were paired and one cow from each pair was allocated by lot to the sprouted-maize ration and its partner to flaked maize. The lengths of the three periods of the experiment were (*a*) three weeks, (*b*) seven weeks, (*c*) three weeks. Later eight other cows became available and these were paired

and allocated in the same manner, but the lengths of the periods were (*a*) two weeks, (*b*) four weeks, and (*c*) two weeks.

The maintenance ration used throughout these experiments consisted of 5 lb. poor meadow hay, 20 lb. vetch-and-oat silage, and 20 lb. mangolds, which supplied about 5·9 lb. starch equivalent and 0·7 lb. protein equivalent.

During the control periods the production ration consisted of concentrate cubes with percentage composition: decorticated groundnut cake 16, soya-bean meal 15, maize-meal 22, wheat offals 12, rice bran 23, treacle 10, and minerals 2. This was fed at the rate of 4 lb. per gallon of milk produced.

During the experimental period the 4 lb. of cubes fed for the first gallon of milk was replaced by 3 lb. flaked maize plus 1 lb. decorticated groundnut cake, or by 3 lb. sprouted maize (weighing 6 to 8 lb. after sprouting) plus 1 lb. decorticated groundnut cake. Records were kept of the milk yields, the fat and solids-not-fat contents of the milk, and the live-weight of the cows. The results are given in Table 1, which deals with the longer experiment using six cows, and in Table 2, with the shorter experiment using eight cows. In both experiments the differences between the two groups were slight. Milk yield appeared to reflect a small advantage in favour of flaked maize, but percentage fat showed an inverse relationship to milk yield, being slightly higher on the sprouted maize. On statistical analysis the differences were, however, found to be without significance.

TABLE 1. *Comparison between the Production Values of Sprouted Maize and Flaked Maize (6 cows)*

	Mean weekly production during preliminary control period (3 weeks)	*Experimental period*							*Mean weekly production during final control period (3 weeks)*
		1st week	*2nd week*	*3rd week*	*4th week*	*5th week*	*6th week*	*7th week*	
Milk yield, lb.									
Flaked-maize group	172½	194	193	191½	196½	195½	206½	212	210½
Sprouted-maize group	176½	189½	186	183½	189	182½	191	194½	202
Relative value of sprouted-maize group when control period = 100	100	95·4	94·2	93·7	94·0	91·2	90·4	89·9	90·0
Fat in milk, per cent.									
Flaked-maize group	4·24	..	..	3·91	..	..	..	3·77	3·86
Sprouted-maize group	3·99	..	..	4·15	..	..	..	3·84	3·84
Relative value of sprouted-maize group when control period = 100	100	..	..	112·8	..	..	..	108·2	105·7
Solids-not-fat in milk, per cent.									
Flaked-maize group	8·68	..	..	8·63	..	..	..	8·73	8·83
Sprouted-maize group	8·92	..	..	8·85	..	..	..	8·83	9·07
Relative value of sprouted-maize group when control period = 100	100	..	..	99·8	..	..	..	98·4	100
Live-weight of cows, lb.									
Flaked-maize group	1,111	..	..	1,129	..	..	..	1,143	1,144
Sprouted-maize group	1,117	..	..	1,125	..	..	..	1,154	1,146
Relative value of sprouted-maize group when control period = 100	100	..	..	99·1	..	..	..	100·4	99·6

TABLE 2. *Comparison between the Production Values of Sprouted Maize and Flaked Maize (8 cows)*

	Mean weekly production during preliminary control period (2 weeks)	*Experimental period*				*Mean weekly production during final control period (2 weeks)*
		1st week	*2nd week*	*3rd week*	*4th week*	
Milk yield, lb.						
Flaked-maize group	195	200	209½	212	218	218½
Sprouted-maize group	186¼	192¾	195	195	200	212
Relative value of sprouted-maize group when control period = 100	100	100·9	97·4	96·2	96·0	101·5
Fat in milk, per cent.						
Flaked-maize group	3·65	..	..	3·46	..	3·45
Sprouted-maize group	3·63	..	..	3·86	..	3·31
Relative value of sprouted-maize group when control period = 100	100	..	..	112·4	..	96·2
Solids-not-fat in milk, per cent.						
Flaked-maize group	9·14	..	..	8·81	..	8·91
Sprouted-maize group	8·95	..	..	8·78	..	8·98
Relative value of sprouted-maize group when control period = 100	100	..	..	101·7	..	102·8
Live-weight of cows, lb.						
Flaked-maize group	1,066	..	..	1,024	..	1,160
Sprouted-maize group	1,122	..	..	1,096	..	1,215
Relative value of sprouted-maize group when control period = 100	100	..	..	99·0	..	99·9

2. *Sprouted Maize for Dairy Yearlings*

The animals used for this experiment were eight dairy heifers aged 12 to 15 months. They were divided into two groups by pairing animals of similar age and live-weight, then allocating by lot one animal of each pair to the experimental diet and one to the control diet. The four control animals were housed in one pen and the experimental animals in the adjoining pen. Previously all the animals had received similar housing and treatment, the ration consisting of oat-and-vetch silage 10 lb., mangolds 20 lb., poor meadow hay 7 lb. Concentrate cubes[1] were given at the rate of 2 lb. per animal per day.

This ration constituted the control diet; for the experimental diet the 20 lb. mangolds and 1 lb. of the concentrate cubes were replaced by the produce (when sprouted) from 2¾ lb. dry maize. The choice of a reliable basis for comparison between the nutritive value of foods so widely different as mangolds and maize is difficult and somewhat arbitrary. For the purpose of this experiment it was decided to compare foods supplying approximately the same 'gross digestible energy as starch'. The figures below give a comparison between the alternative foods used in the experiment, and it will be seen that the maize ration was lower in

[1] The concentrate cubes consisted of a mixture of decorticated groundnut cake 12 per cent., maize meal 38 per cent., wheat offals 38 per cent., treacle 10 per cent., and minerals 2 per cent.

'dry matter', approximately equal in 'gross digestible energy as starch', but appreciably higher when expressed as 'starch equivalent'. The digestible protein of the two rations was approximately equal.

Ration	*Dry matter*	*Gross diges. energy as starch*	*Starch equiva-lent*	*Diges. crude protein*	*Diges. pure protein*
	lb.	lb.	lb.	lb.	lb.
2¾ lb. maize before sprouting .	2·39	2·22	2·13	0·22	0·21
20 lb. mangolds plus 1 lb. conc. cubes	2·86	2·29	1·69	0·26	0·14

The experimental feeding began on February 16 and continued till May 3—about 2½ months. On May 3 all the animals were allowed pasture by day. The animals were weighed at fortnightly intervals throughout the experiment; the weighings used for calculating the total live-weight gain were an initial weighing on February 16 before experimental feeding began and a final weighing after completion of the experiment. For the final weighing the average of two consecutive days' weighings was used; these were taken on May 4 and 5 after all the animals—experimental and control—had been grazing 24 and 48 hours, respectively. The results are shown in Table 3.

TABLE 3. *Live-weights of Animals*

Identification number of animal	*Group*	*Initial live-weight on 16.ii.37*	*Final live-weight on 4.v.37*	*Live-weight increase in 78 days*	
				Total	*Per day*
		lb.	lb.	lb.	lb.
25	Control	672	798	126	1·62
29	,,	482	540	58	0·74
27	,,	504	600	96	1·23
35	,,	432	488	56	0·72
Mean of control group		522	606	84	1·08
26	Sprouted maize	672	725	53	0·68
28	,,	476	567	91	1·17
34	,,	488	624	136	1·74
30	,,	452	544	92	1·18
Mean of sprouted-maize group . .		522	615	93	1·19

The average daily live-weight increase for the mangold (control) group was 1·08 lb., and for the sprouted maize (experimental) group 1·19 lb.

The reason for using the post-grazing weighings for the final live-weight was that the live-weight of animals is influenced by the amount of bowel contents, which may be greater with a non-laxative than with a laxative food like mangolds.

It is of interest to note that if the cattle had not been weighed after they had been grazing and the last indoor weighing had been used for the final weighing, the live-weight increases of the two groups over an experimental period of 71 days would have been 1·22 lb. per day for

the mangold group and 1·54 lb. for the sprouted-maize group. In these circumstances the advantage of the sprouted-maize group is considerably greater, but the post-grazing weights indicate that much of the advantage was due to the non-laxative nature of the sprouted-maize ration. Although the difference in live-weight gain between the two groups of animals was not statistically significant, the results provide some evidence for assuming a slight advantage for the sprouted-maize ration. If this assumption is made it would appear that evaluating the ration by the 'gross digestible energy as starch' method could be improved upon by the 'starch equivalent' method, which, as already stated, indicated a higher value for the maize. Further comments on this point are made in the next section of this paper.

The appearance of the experimental animals was noted from time to time during the experiment: the majority of observers could see no difference between experimental and control animals, but a few considered that the group fed with sprouted maize had a little more bloom.

Discussion

Some of the more extensive cattle-feeding experiments with sprouted maize which have already been published may be summarized as follows:

The report of the National Institute for Research in Dairying [2] concluded from the results of feeding experiments with dairy cows that there appeared to be no marked difference between sprouted maize and other good farm foods containing equal nutrients. The foods used for comparison included vetch-and-oat silage, marrow-stem kale, and a mixture of hay, kale, and maize-germ cake.

Paterson [3], after a number of experiments with fattening cattle, reported that sprouted maize is markedly superior to swedes for such cattle.

McCandlish [4] reported that 'the replacement of part of the mangolds in the ration by sprouted maize supplying an equivalent amount of dry matter brought about some improvement in digestibility; this improvement was most marked in the case of crude and true protein.' On the other hand, when McCandlish [5] compared flaked maize with sprouted maize for calves he found that if there was any difference in the nutritive value of the two foods, the advantage lay with flaked maize.

The experiments reported in the present paper indicate that flaked maize is fully equal to sprouted maize as a food for dairy cows, whilst the trial with young dairy stock show a possible advantage of sprouted maize over mangolds.

In view of the lack of agreement between some of the experimental findings it may be of interest to consider possible explanations:

The best indication of whether sprouting improves the nutritive value of grain is probably provided by the comparisons of sprouted and flaked maize. The trials noted above with dairy cows and with calves suggest that if any nutritional advantages result from sprouting maize fully as great advantages result from flaking it. This conclusion is somewhat similar to that already commented upon by Crowther [1] regarding barley, and noted in the opening paragraph of this paper.

Reference has already been made to the problem often encountered in feeding experiments of deciding a satisfactory basis for comparing bulky with concentrated foods, and the experiment with dairy yearlings reported here has consequently been given a qualified interpretation. According to Wood [6], the starch equivalent or net digestible energy is 'the best measure available at present of the relative values of feeding-stuffs for the production of growth, fat, milk or work'. In view of this pronouncement it is enlightening to examine the basis of Paterson's [3] results showing the superiority of the dry matter of sprouted maize over an equal weight of the dry matter of swedes. The following figures express by various methods the nutritive value of the two foods.

	Dry matter	*Gross diges. energy as starch*	*Starch equiva-lent*	*Diges. crude protein*	*Diges. pure protein*
20 lb. swedes	2·30	1·84	1·46	0·22	0·06
2·84 lb. maize, i.e. calc. quantity required to produce 2·30 lb. dry matter as 'sprout' . . .	2·30	2·29	2·20	0·22	0·21

The chemical analyses used for this comparison are taken from the Ministry of Agriculture Bulletin 48 [6], and the weight of maize grain necessary to produce 2·30 lb. dry matter in sprouted maize was decided by making allowance for the normal moisture-content of maize grain and for the fact that maize loses some dry matter during the sprouting process. This loss during sprouting was reported as 25 per cent. by Reading workers [2], but the figure used for the present calculations was 7 per cent., as reported by McCandlish [4].

These figures show that whereas the alternative foods used by Paterson were equal in dry matter and in digestible crude protein, when evaluated by the other methods the sprouted-maize ration was much superior; for example, 2·84 lb. maize meal contains 50 per cent. more starch equivalent than 20 lb. swedes. It is therefore not surprising to find that the sprouted-maize ration yielded better live-weight gains and 'bloom'. Another factor which may have influenced the results of Paterson [3] and McCandlish [4] is that already noted in the dairy yearlings experiments, viz. the greater weight of bowel contents found in animals receiving sprouted maize than in those receiving roots. This point is confirmed by the low proportion of dead- to live-weight in Paterson's sprout-fed fat cattle and in the lower weight of dry matter in the faeces of McCandlish's cattle when they were given sprouted maize as opposed to mangolds. In these experiments, therefore, it is difficult to find evidence of any advantage in the sprouting of maize.

Considerable attention has been given to the possibility that the sprouting of grain may produce nutritional factors of the vitamin class. To demonstrate this with certainty it is desirable to discover the identity of the vitamin, because some vitamins are not required by cattle and the influence of others may only be observed under special circumstances. Vitamin A is usually considered of importance in cattle-feeding and the Reading experiments [2, 7] leave little doubt that sprouting does not

improve the vitamin-A potency of maize. This work also failed to demonstrate any important effects of sprouted maize on the contents of vitamin B (complex), of B_2, or C of milk. In any case it is well established that the cow does not require either of these factors in her food.

After the discovery of the anti-sterility vitamin E in 1922, sprouted oats was widely recommended as a means of combating sterility. Experimental work to test this recommendation has not been convincing, and it is now believed that vitamin E is of much less importance for many animals than the original work with rats suggested. Henke [8] performed carefully controlled experiments with cattle and found no improvement in fertility after feeding sprouted oats; and his results with pigs were indefinite and not significant. Many sources of vitamin E are now known, e.g. wheat germ, and it appears quite unnecessary to sprout grain in order to obtain ample supplies.

Recently, some American workers have described a new dietary factor in young spring grass which they refer to as the 'grass-juice factor', and claim that it passes into the milk [9], an observation which has not yet been confirmed by other workers. It seems improbable, however, that the factor is present in sprouted grain, for the American workers reported that fresh oat-grass which had been grown in a greenhouse was inactive as a source of the 'grass-juice factor'.

One obvious change brought about by sprouting grain is the conversion of a dry food to a succulent one. This is sometimes considered to be an advantage, but most students of nutrition believe that succulence unaccompanied by other dietary factors is of little or no value.

The general conclusion which may be drawn, therefore, is that if any nutritional improvements result from the sprouting of grain, such improvements have not yet been demonstrated, and therefore may be assumed to be very small, non-existent, or inoperative under normal conditions of cattle management.

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AGRICULTURAL METHODS ADOPTED IN THE ROTHAMSTED CLASSICAL AND MODERN FIELD EXPERIMENTS

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THE purpose of this paper is to put on record the agricultural methods used on the experimental plots at the Rothamsted Experimental Farm. The methods are varied in detail from time to time as new equipment suitable for small-plot work becomes available, but until recently there have been very few suitable implements marketed. Within the last year or two several mechanically drawn implements suitable for the small farmer and market-gardener have been placed on the market, and it is hoped that some of these may be adopted for use on the plots.

Classical Experiments

The same general methods are adopted in all classical corn experiments, and a detailed account of the methods adopted on Broadbalk wheat-field will apply, with minor modifications, to all other classical corn crops.

Broadbalk wheat.—One of the main difficulties encountered when growing wheat continuously is the fact that the crop occupies the ground for at least ten months of the year, so there is very little time for cleaning the ground. One of the best methods of keeping down annual weeds is to break up the stubble in some way immediately after harvest in order to get a tilth that will encourage the weed seeds to germinate. These are then destroyed by the subsequent operations. From time to time various methods have been adopted, but since 1930 the general practice has been to give a single ploughing without the preliminary use of the cultivator. All tractor-implements tend to carry soil over from one plot to the next when worked across the rows, and now all operations (except harrowing and rolling) are done up and down the plots. In the autumn of 1934 and 1935 double ploughing was tried, once immediately after harvest and once shortly before sowing. This plan worked very well the first year but failed in 1935. Since then only one ploughing has been done, and this is carried out as soon as possible after the crop has been carted. The field is left in the furrows until shortly before drilling, and is then worked well.

The first operation after harvest is the application of dung to Plot 2. This is weighed at the farm in carts, and the correct amount is carted to each section of the plot. While this is being done, one of the experimental staff spreads a thin layer of dung around the edges of the sections of the plot, so that when the farm men go spreading they can spread evenly inside the demarcated area.

The plots are always ploughed in pairs. A ridge is set on the path between two of the plots, and then the plough works round and round until the two plots are finished and half of each outside path is done.

The other pairs of plots are treated in the same manner. The next time the field is ploughed, the starting ridge is set on the path where the finishing furrow was left at the previous ploughing. This ensures that the soil from the plots is thrown out at one ploughing and back again when next ploughed, so that the soil is not gradually moved from one plot to the adjoining one. The furrows are then left until October, when the field is usually cultivated.

The next operation is the marking out of the field. There are two large permanent white posts at each end of the field which give the top and bottom boundaries of the plots. Each section is also marked by a similar post along the south side of the field. In the centre of each path between the plots at both ends of the field is a small oak peg sunk into the ground below the depth to which cultivation implements will work. Whenever the corners of the plots have to be found these sunk pegs are first found, and knowing the width of the path the positions of the corners are easily marked, small hazel pegs being used. These are driven down until only a few inches show above ground, so that they can be found fairly easily for drilling, and yet are seldom pulled up or broken by implements when working the soil before drilling. Whenever the plot-corners have to be marked afresh the sunk pegs are always unearthed. Chaining is done only to give the approximate positions of the sunk pegs, as with chaining there is always some slight possibility of error. To eliminate the measuring of each individual path-width a wooden rod is used on which the width of the paths is marked. This same rod has the path-widths of all the classical fields marked on it, for a similar procedure is used for marking out all the classical fields.

The next major operation is the application of manures. These may be applied either directly on the plough furrows, or at any intermediate stage of working, the deciding factor being the strength of the wind. For this operation a calm day is needed to ensure that the manures are not blown on to other plots, and, profiting by past experience, we choose the earliest opportunity of applying them, no matter how much or how little the ground has been worked. The same manures go on to each plot every year, and the set of the distributor is known which will sow nearest the quantity for each plot. The Field Superintendent supervises the weighing, sieving, and mixing of the manures in the manure-shed at the farm. The components of the mixed manure are weighed out separately, checked, and then passed through a sieve; they are then mixed, bulked up with silver sand to the correct volume for each plot, and remixed. The mixtures are bagged and labelled with a small wooden peg carrying the plot-number. The floor is swept clean and each plot is finished before another one is started. We find it better to sow by volume rather than by weight. The manures are then carted to the field, and the bags for each plot are put on the headland opposite the appropriate plot under the supervision of one of the experimental staff. The distributor used is of the rising hopper type. As the machine is drawn forward the hopper is gradually raised so that the top of the manure is always in contact with a revolving star-wheel, the position of which is fixed. The star-wheel pushes the manure over the side of the

hopper in a fairly even flow. The speed at which the hopper is raised can be controlled by varying the size of the worms and gear-wheels by which the drive is taken from the main wheels to the ratchet on the hopper. The drive and the setting of the implement are quite positive, and so if the same setting is used the same amount of manure is applied each year. This is the only machine of several that have been tried which will sow artificials accurately in both damp and dry states. A large cloth is spread on the ground just off the end of the plot, and the manure-distributor is drawn on to the cloth and filled there. The manure in the hopper is levelled off, and the hopper is wound up so that the top of the manure just touches the star-wheel. The star-wheel is given a few turns by hand and the distributor is ready. When the machine needs refilling the operation is repeated, the cloth being moved to the distributor. When the whole of the plot has been covered, the distributor is taken back to the cloth and the hopper emptied on to it. The manure on the cloth is then sown by hand as evenly as possible over the whole plot.

Next comes the final working-down to the seed-bed, and the aim is to get a fairly fine but firm tilth with no knobs much bigger than a hen's egg. The implements used and the number of operations of course depend upon the season. This final preparation of the seed-bed obliterates all plot-boundaries, and the small hazel pegs put in before the distribution of the manures have to be found again before drilling. This is usually done quite easily, but sometimes some of the pegs are broken off by the tractor, in which case they have to be positioned again from the sunk pegs.

For drilling, one side of each plot has to be marked out with pegs to ensure that the drill is kept straight and on the plot. Surveying-poles are placed at the top and bottom corners of the plot, and six or eight intermediate white pegs or surveying-poles are then sighted into line. The near wheel of the drill is kept in line with the pegs, the horseman concentrating his attention on this while one of the experimental staff sees that the drill is sowing properly at the correct depth. Once one edge of the plot is drilled, the rest of the plot is drilled in the usual manner while the pegs are being sighted into line for the next plot. There is always the same number of rows per plot, but unfortunately the number of rows is not a simple multiple of the spouts of the drill, so that when most of each plot has been sown the drill has to go back and put in the three extra rows to complete the plot. To do this all the spouts on the drill with the exception of three have to be shut. The same variety of seed, dressed to kill the spores of seed-borne diseases, is used each year, but new seed is always obtained. The seeding-rate is about three bushels to the acre. The seed is harrowed in and left to the mercy of the birds and weather.

In spring, usually March or April, the nitrogenous top-dressings are applied, but the plots do not have to be marked out for this operation as the wheat plant is showing up clearly. The plots are then harrowed, either lengthwise or crossways, to break up clods and surface-pans, and to kill off as many weed seedlings as possible. The light Cambridge

roller is then used to compact the soil around the roots of the plant, and to push down the flints so that they will not catch the knife of the binder.

Later, the ends of the plots and the headlands between the sections are marked off with a plough, and the top and bottom headlands are ploughed to keep them clean. During the spring and summer the paths between the plots have to be kept horse-hoed to subdue the weeds.

Fallow section.—The field is divided into five sections and one section is fallowed each year. A headland is left between the sections so that implements working the fallow do not turn on the part of the plot from which yields are recorded. The headlands between the cropped sections are marked off, and the crop is discarded at harvest. The fallow section is worked down with the rest of the field in the autumn, but it is not manured and not worked again until the spring. By this time many weed seeds have germinated and these are killed off by surface cultivation. In late April or May it is usually ploughed and again worked several times until June or July, when a second ploughing is done. Then more workings are given right up to harvest. Usually just two extra ploughings are given, so that the ridges and furrows are in the same positions as on the cropped sections. The chief weeds we have to combat are slender foxtail (*Alopecurus agrestis*), commonly known as blackbent or blackgrass, and poppies, though the latter seem to have been greatly reduced during the last few years. Both these are annual weeds and the method of working the fallow is satisfactory in keeping them under. The fallowing method we adopt would not be efficacious against perennial weeds like couch grass. Wild oats are now very prevalent on Sections I and II of the dunged plot and on the odd strip on the northern side of the field. It is almost impossible to combat this weed in the cropped sections, as it is not easily seen until the flowering stage, and as the seed ripens before the wheat it either sheds itself or is knocked out by the harvest operations.

Shortly before the field is cut the Field Superintendent goes round all the plots and makes notes of any outstanding features, such as laid plots and bird damage, and these remarks are subsequently entered in the White Book in the Library. Before the cutting of the plots is started the crop from the headlands between the sections has to be scythed out or cut with the binder, and carted to the outside of the field. The cutting is done with a power-driven self-binder, i.e. the drive of the binder is taken from the power take-off of the tractor. The plots are usually cut in groups of about six, three being cut going down the field and three coming up, but the number of plots per group depends upon whether there are any badly laid plots which have to be cut against the way the crop is lying. A division has to be made by hand or by a small reaping-machine between each of the groups so that the tractor can pass down without running on the standing corn. The binder throws the first two rows of sheaves on to the adjoining plot, and, to avoid any error when the sheaves are thrown back on to their correct plots, different-coloured binder twine is used for each pair of plots. The places where the sheaves

fall off their plots are raked back by hand. The changing of the twine between each pair of plots causes a little delay, but possible mistakes are avoided by the use of the different colours. When the binder comes to the end of each section the tractor stops, but the binder is kept turning over until all the corn is thrown out. If any of the plots are badly laid, men with forks or sticks have to lift the crop off the ground so that the knife of the binder can get under the straw. Any long straw left by the binder has to be scythed off, and if, as sometimes happens, the crop is 'laid all ways', the whole plot may have to be scythed.

When the sheaves have all been thrown back on to their correct plots by the experimental staff, they are stooked or shocked, about eight sheaves being put in each shock.

There is seldom more than one cartload to any plot of any one section. One man pitches the sheaves on to the cart, one man loads, and another man with a horse-rake rakes up behind them, so that the whole of each plot is cleared up before another is begun. All the work is carried out under the supervision of one of the experimental field staff. The appropriate plot-label is then put on the cart and another man leads the cart away to the stack.

At the bottom of the stack some old straw is placed to keep the sheaves off the ground, followed by a layer of sheaves from the headlands. Over this layer a large Hessian sheet is spread. When the first load arrives at the stack, a cloth is spread on the ground close to the stack, and the cart is drawn on to it. The cart is unloaded, and the sweepings from it are kept on the cloth, which is then passed up and put on the stack. The label peg is put under the last sheaf in the centre and another cloth is spread over the top of the sheaves. The process is repeated until all the produce from the plots is carted, the operation being always supervised by one of the experimental staff. A layer of sheaves from the headlands is placed over the whole stack when finished to keep off birds from the plots. The stack is now always made under the Dutch barn at the farm buildings.

Threshing is now done as soon as possible after harvest to avoid losses through rat-damage. Up to a year or so ago it was left until December, i.e. when the autumn land operations were completed. However, in 1937 the rat-damage in the stack was so severe that last year threshing was done in September. It is very inconvenient having to do this threshing under cover at that time of the year because the operation needs all the men and all the experimental staff on the farm, and it means that what is really a wet-day job is being done when the soil is dry and when outside work should be in full swing. However, it is hoped to have a rat-proof barn erected in the near future which will enable all experimental corn crops to be stored safely until most of the outdoor work is finished.

For the threshing one man and one of the experimental staff are needed on the stack to pass the sheaves on to the drum; another man cuts the bands and feeds the sheaves into the drum, while another attends to the delivery spouts and carries away the threshed grain to be weighed. Other men pass the threshed straw as it comes from the

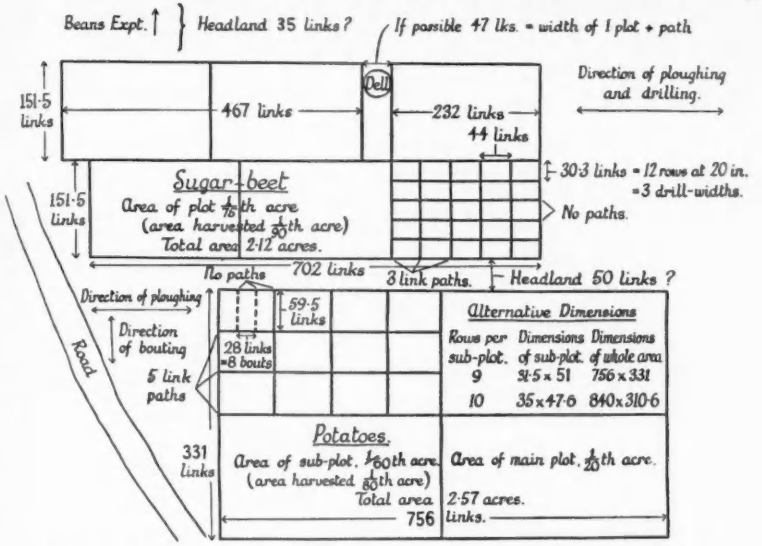
machine on to a cart, which is then taken to the weigh-bridge. The cart is then unloaded at the straw-stack while another cart is being filled at the machine. The assistant on the stack sees that all the sheaves down to the parting-sheet have been threshed, and then the sheet with the loose ears and grain is passed on to the platform of the machine. This is then swept so that all loose ears and grain go into the drum. An interval of 10 minutes is allowed to elapse before the next plot is started, during which the drum continues to revolve, so that there is no carry-over of grain from one plot to the next. During the interval the rest of the straw is cleared away, the chaff and cavings are gathered up and weighed, and everything is prepared for the produce from the next plot. The chaff and cavings, which contain most of the weed seeds, are then carted away for burning or are used for covering outside potato or mangold clamps. The grain is taken to the barn and weighed, and several bushel weights are taken from each plot. A sample of grain is taken from each plot for the determination of the dry-matter content, and a portion of 1,000 gm. approx. is dried, bottled, sealed, labelled, and taken to the laboratory for storage. A sample of the straw is also taken from each plot and is chaffed at the farm. The dry-matter content is determined and about 150 gm. of the dried sample are stored in tins, which are labelled and later taken to the laboratory.

During the winter months the dates of all operations on the field, a table of quantities of manures applied to each plot, together with any notes, are entered in the White Book which is kept in the Library. The field labels, of which there are about 53 for Broadbalk alone, are painted and stencilled during the winter months.

Annual and Rotation Experiments

The ideal position for annual experiments is the most even site on the field which is normally carrying the crop on which the experiment is to be made. For many reasons this is impracticable, and so one field is set aside each year and as many annual experiments as possible are fitted into it. There are more annual experiments than one field can carry, but the management of the farm is greatly helped by reducing the number of fields carrying experiments. All the non-classical arable fields carry annual experiments about once in five years, for there is a rule that at least four years must elapse before an experimental site can be used again. During the four intervening years no artificials other than nitrogenous top-dressings are applied, so that there should be no accumulation of phosphate or potash which might mask the manurial effects looked for in the experiments. A dressing of dung is usually given to the fields for the first or second crop after the experimental year.

The annual experiments are normally planned by a sub-committee of the Field Plots Committee, and the rough plans of proposed experiments are placed before the full committee. If they are approved, they go back to the sub-committee for determining sizes and arrangements of plots and rates of manuring. Next, the positions of the various experiments in the field set apart for annual experiments have to be decided, and this is done on the field. Alternative dimensions of plots are often given so that the best



Plan of experimental field, giving detailed measurements and working data.

can be made of the available space. The chosen sites have to be free from dells, and the lay-out has to be planned so that any prominent ridges or furrows left from previous ploughings come on the paths of the experiment.

Once the site and plot-dimensions are finally determined, a base-line is laid down the overall length of the experiment. Right angles are set off from the ends of the base-line by means of a crosshead, and the overall width of the experiment is measured along these lines. The corners of the plots around the outside edges of the experiment are marked out with hazel pegs, chaining being used to determine the positions of the plot-corners. When complete plot-boundaries are needed, as for manure-sowing, lines are laid from peg to peg in one direction and small marks are drawn by a hand-hoe. This marks the plot-boundaries in one direction. For the cross-boundaries, lines are laid from peg to peg across the hoe-marks. Thus only one row of plots is marked out at any one time, and after the manures have been applied to this row of plots the lines are moved on to the next. Manures are always applied on the small plots by hand, as there is no distributor which can do the job satisfactorily. Many of the plots receive different quantities of manure, and the specified quantity has to go on each plot even to the nearest quarter of an ounce. If a small distributor was used the setting would have to be altered a great many times for each experiment, and the hopper would need emptying after going over each plot so that the remaining manure could be sown by hand. It is far quicker to do the whole operation by hand.

If the experiment is for one year only, no permanent or semi-permanent marks are put down. However, if the experiment is to last some

years, sunk pegs are placed in the ground to mark the corners. If there is only a possibility of following it up in the second year, small angle-iron pegs are placed in the hedges in line with the outside boundaries; these enable the boundaries of the experiment to be picked up quite easily should they be required.

If the drilling follows directly after the sowing of the manures, the hoe-marks are used as the lines to which the drill is kept, but if, as more frequently happens, the hoe-marks are obliterated by the final preparation of the seed-bed, lines are laid along the plot-boundaries in the direction of drilling, or white pegs are sighted in. Only one edge of each row of plots has to be lined up in this way, as we now arrange that the plot-width is a simple multiple of the number of spouts on the drill at whatever spacing is used. For annual beet and bean experiments the spacing between rows is usually 20 in., as this is about the minimum width that a horse-hoe can work late in the season without damaging the plant. The beet plants are singled to about 9 in. between the plants early in June. Corn crops are sown at 6 in. spacing.

For potato experiments the same general method is adopted for marking out the site, but manures, both dung and artificials, are applied after the ridges have been drawn out. The ridges are carefully kept to the same width, and each plot has the same number. The potatoes are planted on top of the manures. To get even spacing of the sets and the same number of sets per row, chains, to which pieces of coloured string are tied, are laid along the top of the ridges. One man works each side of the chain and places a set opposite each piece of string.

As early as possible in each season a white peg is placed on each plot. On this peg is stencilled an abbreviated description or symbol of the experiment and plot-treatment. The key to the treatment-symbols is placed in a glass-fronted frame at one corner of the experimental area, so that it is a fairly easy matter to determine the exact treatment any particular plot has received.

In the early days of the annual plots, all corn plots were cut with a scythe and then tied by hand. Later, a rack machine was used. This is much like a mowing-machine but has a slatted wooden rack behind the knife on to which the corn falls. The man on the seat rakes it off whenever enough for a sheaf has collected. In 1928 the self-binder was used for the first time and to-day this method is still being used, though of course with a more modern machine. The tractor-drawn binder stops at the divisions between the plots and clears itself before passing on to the next plot. Different-coloured strings are used for the small plots so that the sheaves can be thrown back on to their correct plot.

After stooking the plots are raked with hand-drags. When the corn is fit for carting the whole produce from each plot is thrown on to a large Hessian sheet, the corners of which are then tied together. The plot label-peg is put in the bundle, and the bundles are loaded on a cart and brought home to the barn. Until 1937 the horse-waggon was used for this carting, but the floor of it is so high that it needed several men to load the bundles, for though they rarely weigh more than 2 cwt. they are bulky things to handle. About six of the bundles could be brought

home on each load. In 1938 a large-bodied, low-loading cart or trailer running on rubber tyres was built. It can be drawn by a horse or tractor. The low floor makes loading very much more easy, and nearly twice the number of bundles can be brought home on each load. With the sides up, the cart can go through gateways, but as there are no gates on the routes from the rotation experiments and seldom any from the annual experiments, the side boards are made to open outwards so that they can be used as extensions of the floor-space.

Threshing is carried out during the harvest operations as there are not enough sheets for all the plots. Some plots must therefore be threshed so that the sheets can be used again. The threshing is done by a small, simple machine built for the work, and is driven by an electric motor. Since 1928 the following method of threshing has been adopted. The total produce of a plot is weighed while still in its sheet on a spring balance suspended from a tripod. The bundle is opened and the sheaves are fed through the drum. The corn alone is weighed, the weight of straw being obtained by difference. Samples of grain and straw are taken for dry weights and for stock purposes from the rotation experiments, whilst dry weights are determined on both grain and straw from all annual experiments.

Lifting of sugar-beet usually starts early in November, but the operation takes a long time owing to the scarcity of casual labour which is needed for the job. Shortly before lifting starts the number of plants in each plot is counted. The plants are then loosened in the soil by a beet-lifter, but care has to be taken to see that the lifter does not carry roots beyond the plot-boundaries. One gang of men follows to lift the beet from the ground, each man taking two rows at a time. The beet are knocked together to remove most of the adhering soil and then both beet are put down in one row. On our heavy soil, in November and December, knocking the roots together rarely removes much of the soil, and more frequently each individual root has to be scraped with a knife. Samples of beet are taken from the rows after cleaning; they are weighed and sent to the laboratory for a sugar-determination. Another gang of men follows; they pick up the beet one by one on the point of a beet-knife, and snip off the leaf and the crown. The tops drop into a bath, which, when full, is taken and emptied into a larger bath on the weighing scales. The roots are also thrown into a bath, which, when full, is emptied into a larger bath on the weighing scales.

Lifting operations on mangolds and swedes are very similar to those on the beet crop, but being shallow-rooted plants no preliminary loosening is necessary. Each man pulls, cleans, and tops his own row. If the plots are large the tops only are weighed in the field, the roots being weighed in carts at the farm weigh-bridge when they are carted off the field.

Until 1928 the potatoes from small plots were lifted by hand-forks, boys and men being employed to pick up the tubers, rub them clean, and take them to the weighing scales. After each plot had been lifted, each row was again forked over and any remaining potatoes were picked up. The lifting of the potatoes is now done by a mechanical potato-digger, which is pulled by the tractor. Revolving tines on the digger

knock off most of the adhering soil, and the potatoes are then picked up and bagged. With this method several supervisors are necessary at plot-divisions to see that no potatoes are spun from one plot to another. After each row of plots is finished, the soil is harrowed, so that any potatoes that were covered are seen and picked up. The supervisors also see that the produce from the plots goes into the correct bags, which are labelled with the plot-number. This operation is now further complicated by the presence of two guard-rows of potatoes between each strip of plots. These rows have to be dug out and the tubers bagged separately from those dug from the plots; and this small strip of land has then to be harrowed before we can start the next row of plots. The grading of the potatoes according to size usually takes place at the farm buildings and the three grades are weighed separately. The same riddle-sizes are used each year so that any differences in the proportions of each grade from year to year can be noted. The potatoes are sampled as they are sorted, the samples being taken from the ware grade only.

The harvesting of hay crops is a fairly simple matter. The grass is cut by a mower, care being taken to see that grass is not carried over from one plot to another. It is usually turned by hand, though if the area is big a mechanical tedder may be used. When ready for carting the hay is forked into heaps and the plot is raked over. The weighing apparatus is moved from heap to heap and the produce is weighed. Until 1937 a big wooden tripod and platform were used, which needed three men to move them from plot to plot. Recently a neat little implement has been lent to us which is mounted on rubber wheels and can be moved quite easily by one man. A small net is used for holding the hay instead of the clumsy tripod platform. The actual weighing is also considerably speeded up by the use of this implement.

Notes of all experiments are made by the Field Superintendent and entered in notebooks. The weights of the produce from the plots are also entered in the books as they are taken; and all these data are subsequently analysed by the Statistical Department.

The position of every experiment carried out is recorded in the following manner. On each field there are numbered 'permanent posts', the positions of which are known and fixed. They may be gate posts, concrete fencing posts, or concrete posts set up specially for the purpose. They are painted black and white in cross bands so that they may be seen easily from a distance. The imaginary lines between these permanent posts are called 'post lines', and in most fields two or more of these lines cross. Every year the position of each experiment is measured from these post lines and the measurements are recorded so that at any future time the exact position of any previous experiment can be picked up. Every year a map is made of each field carrying annual experiments, giving the position of each experiment in the field. The map used is a photographic enlargement from an ordnance-survey map, and as it is drawn to scale, no measurements are inscribed on it. However, rough plans with detailed measurements are also kept. The maps are bound and kept for reference.

(*Received June 15, 1939*)

THE TICKS OF EAST AFRICA

Pt I. SPECIES, DISTRIBUTION, INFLUENCE OF CLIMATE, HABITS AND LIFE-HISTORIES

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Ticks have been referred to as 'the scourge of East Africa'. The phrase is rather exaggerated. Yet the abundance and vitality of the pests did not fail to impress the early travellers in East Africa: big-game hunters have written of the 'loathsome' creatures on every species of wild animal; and the pioneer settler-farmers quickly discovered that ticks provided one of the most serious problems of stock-raising. Furthermore, the development of native reserves and native agriculture has been hindered by the ravages of ticks; the improvement of indigenous stock has been impeded by difficulties in controlling the pests; and the free movement of cattle has been restricted because ticks convey and transmit organisms of fatal diseases.

Seventy-four known species of ticks have been collected and recorded from three British East African territories. In the report of the Veterinary Department, Uganda, Mettam listed 40 authentic species from Uganda, and the writer has added 4 more. Forty-seven species have been recorded from Tanganyika Territory, whereas 58 species (including sub-species) have been collected in Kenya Colony—excluding *Ornithodoros megnini* and *Margaropus winthemi*, which have been taken off imported cattle at Mombasa, the chief port of entry to Kenya and Uganda. At least a few more species have been collected but not described, and there are many specimens which, on account of morphological variations, cannot definitely be assigned to any particular known species. As Warburton wrote in 1912, 'there are what appear to be a considerable number of species *in the making*'.

The 74 species are apportioned to 12 genera as follows: 10 belong to the genus *Ixodes*, 7 to *Haemaphysalis*, 2 to *Dermacentor*, and 20 to *Rhipicephalus*. *Hyalomma* is represented by 7 species or sub-species according to Schulze's (1930) classification and, in addition, a species in the new genus, *Hyalommina*. *Boophilus* has 1 species, and *Aponomma* 2, one of which is represented by 2 sub-species; *Amblyomma* has 15 species and *Ornithodoros* and *Argas* comprise 4 and 3 species, respectively.

At least 18 of these ticks have been incriminated in the transmission of diseases, but many more are of interest if only from a purely scientific point of view. The abundance of tick material and the scope for ecological studies provide numerous problems that await investigation; and it would be well to bear in mind the remark of G. H. F. Nuttall (1905): 'Experience has shown that new and fruit-bearing knowledge is seldom revealed to those whose sole purpose is merely utilitarian.'

Of the 74 species (shown in the following list), the life-history of 34 appears to be known. The larvae and nymphae of 46 have never been

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fully described; and practically nothing beyond a record of the tick and the locality of its host is known in the case of many.

Species and Varieties of Ticks in East Africa

Argas
aequalis
persicus

Ornithodorus
megnini
morbillosus
moubata
savignyi

Margaropus
winthemi

Amblyomma
cohaerens
cuneatum
eburneum
gemma
hebraeum
lepidum
marmoreum
nuttalli
paulopunctatum
personatum
petersi
pomposum
splendens
tholloni
variegatum

Aponomma
exornatum
laeve laeve
laeve capensis

Boophilus
annulatus
decoloratus

Dermacentor
circumguttatus
rhinocerotis

Haemaphysalis
aciculifer
bipinosa
calcarata
hoodi
leachi
parmata
spinulosa

*Hyalomma**
anatolicum
dromedarii
impressum
transiens
impressum
albiparmatum
planum
savignyi
impeltatum
rufipes

Hyalommina
lewisi

Ixodes
brunneus
cavipalpus
daveyi
nairobiensis
pilosus
rubicundus
schillingsi
ugandanus
ugandanus
djaromensis

Rhipicephalus
appendiculatus
ayrei
armatus
bursa
capensis
dux
evertsi
falcatus
kochi
longicoxatus
lunulatus
maculatus
neavei
oculatus
pulchellus
sanguineus
simus
sulcatus
supertritus
tricuspis

* The immature ticks of Schulze's species and sub-species for East Africa are being studied to test the validity of the revised classification.

There is reason to believe that some of the species are invalid and the specimens described as such are variants of a previously known species. Several ticks are known only in their male, female, or immature phase of life; and comparatively little is known of their adaptation to different hosts and the immunity of the hosts to infestation by different species of ticks. Larvae and nymphae of certain species are found naturally only on birds and rodents, whereas the adults are more often found on larger mammals. Other species usually infest reptilian hosts but may live equally well on warm-blood animals. The large wild game are infested with ticks that are rarely met with on farm animals, and also with species that frequently occur on domestic stock.

Distribution of Ticks

The general geographic distribution of the most common ticks and vectors of diseases in Kenya Colony has been determined in periodic surveys. The factors that influence the natural distribution of each species have not been fully investigated and there is no precise information on the limiting effect of the separate and combined environmental conditions. Field observations and laboratory experiments have revealed certain predilections on the part of different species, but the data do not warrant definite pronouncements.

R. pulchellus (the zebra tick) thrives best on the plains, in Acacia-desert grass and Acacia-tall grass savannahs east of the Rift Valley in

Kenya. It is more rarely found in the Rift and to the west of the Valley in the Colony, but occurs in Tanganyika and in Uganda. The tick is normally absent from districts higher than 6,600 ft. above sea-level and may be said to be a species of the lower highlands and, to a less extent, of the coastal zone. In the higher altitudes it prevails in the open or semi-open, dry and hot areas, but it contrives to maintain itself in the hot and less humid regions near the sea and the inland lakes. It seems to be fairly resistant to short periods of cold. *R. maculatus* is more of a lowland tick than *R. pulchellus* and is confined to country below 4,000 ft. It has not yet been found in the colder, moist highlands. *B. annulatus decoloratus* is pre-eminently a species of the moist regions, prefers the high plateaux, and is abundant in the cold districts of Kenya Colony where dipping has not eradicated it. The tick flourishes also in the highland forests and glades, but is seldom found in the open dry areas, such as on the plains of the Masai Reserve, the Yatta plateau, the semi-arid areas of Ukamba, and the more extensive scrub areas of the Northern Frontier Province. On the other hand, it abounds in the wooded areas of the Mau hills, in the high (8,000 ft.) country of Limuru; and, in fact, throughout the European highlands. Mettam (1932) records it from Uganda and the writer has received numerous specimens from that Protectorate and from Mpwapwa, which is relatively low (3,500 ft.) but sheltered by wooded hills. Its wide range in Kenya, from the coast to Lake Victoria Nyanza, indicates the adaptability of the species and its resistance to heat and cold, provided moisture is available.

The species and sub-species of *Hyalomma* find the conditions of the arid and desert areas most suitable. They occur most abundantly in the lower dry and sandy districts. *H. planum* is common in the Rift Valley, in the scrub-forest areas of Kitui district, and in the hinterland of the coastal zone. *H. anatolicum* and *H. dromedarii* are chiefly species of the Northern Frontier Province, but, as will be noted later, they have penetrated farther south in Kenya, in Uganda, and in Tanganyika. The other species are less frequently found; and are scattered in very small numbers even in the highlands. *H. leachi*, the common dog-tick, is widespread. It occurs in all districts and at different altitudes. Yet, from numerous field observations, it seems to prefer the shelter of dense scrub and grassy woodlands as so many other species do. It has frequently been collected from the lairs of wild animals, in nesting places and houses of animals—more especially of the canine and feline tribes. *R. sanguineus*, commonly known as the dog brown-tick, is not so abundant as *H. leachi*. It is a species of the more densely populated European areas. Its range of hosts, however, is equal to, if not greater than, that of *H. leachi*. Adults, nymphae, and larvae have been taken off lion, jackal, cheetah, and the different antelopes on the plains of the Masai Reserve, the Northern Frontier Province, and in European areas. It has often been found in the Coast areas, in forests, in deserts, and in towns; it has been collected from a variety of birds, large wild game, and off cattle. The tick has been observed to infest dogs heavily in townships and on farms; but the writer has never found the tick in native huts where dogs rest and sleep more or less with the family.

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The *Amblyomma* species seem, on the whole, to be less selective than other ticks, or they can tolerate better conditions of relatively wide differences. They are not often found in forests. *A. variegatum* thrives all over the ranching country of the Masai Reserve, throughout the cultivated areas of Kavirondo, Kikuyu, and Ukamba; and in the semi-desert areas in the north and east of Kenya Colony. It is widely distributed over the European farms (where dipping has not eliminated the species), whether these are of the purely stock class or mainly concerned with crop-production. *A. variegatum* exists at 8,200 ft. at Timboroa, at 3,800 ft. around the shores of Lake Victoria, and at sea-level. *A. gemma* evidently prefers a warmer and drier climate than *A. variegatum* and is not so extensively distributed. *A. lepidum* prevails in typical desert country and is mostly found in the north-west of Kenya, in parts of Uganda, and farther south in Tanganyika.

I. pilosus is a species of the hills and mountain or forest areas rather than of the lowlands. It infests cattle, sheep, and goats on the slopes of the escarpments of the Great Rift, in the forested areas of the Aberdares, on the Mau hills, in the Thompson's Falls and Limuru districts. Wild animals are often infested with this 'paralysis' tick. Other species are more frequently found on game and wild birds, *I. rasus*, in its larval phase, being a common tick of small and large birds.

R. appendiculatus is the most important tick as far as stock-farming in Kenya is concerned. Its distribution is better known than that of other species. Yet much remains to be done even with regard to this tick. Its normal distribution in most of the advanced European areas has been disturbed by dipping and other methods of control that have been employed for many years. It persists in relatively small numbers where control has not been consistently maintained. The tick known as the common brown tick is usually found in greatest abundance at elevations between 4,800 ft. and 7,000 ft.; but it extends into higher country where the vegetational cover reduces the more severe conditions of exposed pastures. It penetrates into lower country also, where the general environment is modified by the vegetation and local climate. The most heavily infested, or enzootic, areas appear to be those where cultivation predominates and where the infestation of stock is not attended to, as on the majority of stock-farms. The plains are usually free of this tick and it is not often found on the high plateaux or in desert areas.

O. moubata and *savignyi* are generally looked upon as ticks of the dry, hot, and sandy deserts. Their presence in Kenya seemed to be confined to the Northern Frontier Province (3,300 ft.), the eastern areas down the Tana river, and the coastal belt. At one time the former species was a common pest in the Kavirondo Reserves and on the lake-shores (3,800 ft.). More recently, however, the writer has obtained large numbers of *O. moubata* from huts on the site of goat enclosures, 8,000 ft. above sea-level.

Argas persicus occurs in isolated localities in Kenya. It is believed not to be indigenous, as the records indicate that it exists only in European areas. The true distribution of this tick may come to light with a growing interest in poultry and their parasites.

Reference has already been made to *O. megnini* and *M. winthemi* as species that have been collected only at Mombasa, so far as is known. These ticks arrived on stock from South Africa, and the usual veterinary inspection of imported animals revealed their presence before the animals were permitted to proceed inland.

It may here be stated that one record of *A. hebraeum* from the Tana river area in Kenya has not been confirmed, nor has the species been found in the Colony within the last 10 years. There is a record of its presence in south Tanganyika, but this also awaits confirmation.

Whereas it is not possible as yet to define with accuracy the areas and natural conditions most favourable to the separate species in East Africa, it has been observed that there are areas and localities where two or three species predominate over others, which again differ in numerical frequency. These areas are not always sharply defined, as there are extensions of ticks into neighbouring zones; and there is frequent overlapping. A marked change may take place in the tick-fauna, as illustrated in the case of *R. pulchellus* in the Masai Reserve. This species is extremely common in the Ngong district of the Reserve as far as the Uaso Nyiro river that separates the Ngong from the Narok district. In the latter no *R. pulchellus* has been found except on an occasional animal that has crossed the river. *R. appendiculatus* also may cease abruptly. In the West Suk district, this tick is generally abundant on cattle in the Kapenguria area (5,500 to about 7,500 ft.) but is absent from the adjoining area of Kacheliba (3,000 to 4,500 ft.) although cattle from both areas use the common salt-licks in Kacheliba.

Evidence from a few surveys and numerous collections enables most of the western part of the Colony to be classified according to the groups of dominant species of ticks.

The south-eastern, or Ngong, district of the Masai Reserve is *A. variegatum–R. pulchellus* country: the Narok district may be termed *A. variegatum–R. neavei* country, and the trans-Mara designated as a *R. appendiculatus–A. variegatum* area. In the Rift Valley—from Solai through Nakuru to the Kedong river—the combination is *Hyalomma* spp.–*A. variegatum–R. appendiculatus*, although control measures may have altered the natural abundance. In Limuru there is the *Boophilus–R. capensis* predominance; in Kiambu and Fort Hall, *R. appendiculatus–A. variegatum*. In the Naro-Moru district *R. pulchellus–R. appendiculatus* prevails, whereas in the Thompson's Falls area *R. capensis–Boophilus–R. appendiculatus* occurs. *A. variegatum–R. maculatus–R. simus* forms a zone near Malindi on the coast and *Hyalomma–A. gemma–A. variegatum* around Marsabit in the Northern Frontier Province. *R. appendiculatus* and *A. variegatum* are the chief ticks in the Kavirondo Reserves. Towards, and just within, the north-eastern corner of Uganda, *A. lepidum* appears to be the one prevalent tick; and around Mpwapwa in Tanganyika is the dominant group of *A. variegatum–A. gemma*.

This broad—and incomplete—classification has its drawbacks. It is inadequate as a guide to a programme of tick-eradication and does not assist the administration, which has to deal with comparatively small foci of infestation by the most serious vectors of tick-borne diseases.

More detailed investigations in certain districts have shown that there are small areas of *R. appendiculatus* infestation within, or adjoining, other larger, free areas. There are also farms or localities which are clean although surrounded by tick-infested country. These, of course, have been rendered tick-free by efficient control measures.

Climate and Its Effect on Ticks

In many countries outside the equatorial belt it has been shown that climate and other environmental conditions have a considerable influence on the distribution and activity of tick-life. In East Africa the weather seasons are essentially different; and, apart from a few observations, there has been no proof of a correlation of fluctuations in tick-activity with climate or its factors.

The climatic seasons are popularly classified according to the incidence of rain, which varies in total annual amount and in its monthly distribution over a vast area.

Rainfall conditions over East Africa are somewhat complex; but in general Tanganyika has one season of rainfall, whereas Kenya and Uganda have two. The Tanganyika rains extend from November to May, whilst those of Kenya and Uganda have their maxima about April to May and October to November. There are four areas in Kenya where the rainfall distribution differs greatly: the coast, the eastern highlands, the plateau, and the vicinity of Victoria Nyanza.

Many farmers and others consider that ticks increase at the onset of, or during, the rains. Collections of different species of ticks off cattle in different parts of the Colony and at Mpwapwa in Tanganyika have been examined along with weekly and monthly rainfall records, but so far no correlation of tick abundance and fall of rain has been observed. Recorded outbreaks of East Coast fever for the years 1929 to 1938 in Kenya indicate that the disease exists throughout the year, but also that it is more prevalent from about April to August. It may tentatively be deduced from this evidence that *R. appendiculatus*, the tick-vector of East Coast fever, is more or less active at all times, and that it increases in numbers or activity from April to August. Data on East Coast fever in enzootic areas are lacking, and, as has already been stated, collected batches of the tick do not always support this deduction.

There are pronounced differences in seasons according to temperature and conditions that affect temperature. Available information on the mean maximum and mean minimum temperatures does not cover all the areas where series of tick-collections have been made. It may be stated, however, that the mean maximum reaches its highest from January to March, drops to its lowest point in July and August, rises to a secondary peak about October. There is a short drop in November and a rise again to January. The mean minimum sometimes coincides with the rise and fall of the mean maximum. Or it may be lowest from October to January, after which it rises in March to April, drops slightly in June to rise a little about July and August, and then falls towards the end of the year. Over a large part of Kenya the mean temperature and its diurnal range are at a minimum during the cloudy period from about

May to August which, it will be observed, is approximately the time when East Coast fever records are generally high. It is in isolated localities, and only at very short periods, that the temperature falls as low as freezing-point. Maximum temperatures of over 90° F. (32° C.) are, however, quite common during the dry seasons up to altitudes of 5,000 ft.

During all seasons of the year the maximum relative humidity rises above 90 per cent. before sunrise; during the rains the relative humidity in the afternoon rarely falls below 55 per cent. and in the dry seasons it frequently drops lower than 20 per cent.

Limited observations in the field indicate that *R. appendiculatus* thrives best when the mean maximum ranges between 60° and 80° F. (16° and 27° C.) and the mean minimum from 50° to 60° F. (10° to 16° C.). At Mpwapwa neither *A. gemma* nor *A. variegatum* showed numeral fluctuations correlated with rainfall and humidity. The former species, less abundant than the latter, occurred throughout 1935 and 1936 with no sharp differences except in May and June of 1935 and in August 1936. The mean maximum for these three months was 75° F. (24° C.) and the mean minimum about 60° F. (16° C.). *A. variegatum*, however, showed very distinct periodicities. It was abundant from September to March and absent from March to September. The ticks appeared with a rise to 80° to 90° F. (27° to 32° C.) and they disappeared when the mean maximum was from 73° to 77° F. (23° to 25° C.). Other localities in Kenya showed similar fluctuations of *A. variegatum*, though not for the same months, whilst others not many miles from them did not show the same rise and fall of numbers.

Laboratory experimentation with temperatures and humidities has been confined to their influence on *R. appendiculatus*. Even these are incomplete. The observations made are, however, of interest. The replete female of the species is able to tolerate exposure to cold (0° to 4° C.) for not more than about 11 or 12 days. She will not oviposit when the temperature is below 6° C., but will proceed to lay eggs when returned to 19° to 20° C. after exposure to 0° to 4° C. for 10 days. The number of eggs is, then, usually small and the precentage of hatchings low. The resultant larvae do not survive long even under good conditions of temperature and humidity. Oviposition is weak at a high (38° C.) temperature and the eggs soon shrivel up though the humidity may be high. Larvae moult in 5–9 (usually 6) days at 38° C., in 6–10 (usually 9) days at 20° C., in 19–21 days at 14° to 16° C., and in 23–25 days at 12° to 14° C. Unfed ticks succumb very quickly to high temperatures and low (50 per cent.) relative humidity. They are much more resistant to cold but do not usually survive at 6° C. for continuous periods of over 4 weeks. Under less rigorous laboratory conditions, replete and unfed *R. appendiculatus* are able to live for some time; and mortality is reduced. Larvae transferred every 24 hours for 7 days from 38° to 14° C. moulted with a mortality as high as 60 per cent. When moved from 4° to 38° C., mortality was 48 per cent., from 4° to 27° C. the mortality was 35 per cent. and from 6° to 20° C., 21 per cent.

Still less severe treatment and more equable temperatures decrease the rate of mortality. Alternations of 12° to 16° C. and 12° to 20° C. effect

a mortality of about 6 per cent.; exposure to 8° C. and 25° C. resulted in about 9 per cent. deaths among engorged larvae.

Habits and Life-histories

The adaptability of many of the East African ticks to different classes and species of hosts is astonishing. Only a few illustrations can be given here, but they show how the ticks can adopt a variety of hosts and thus keep up the infestation of a locality. *A. marmoreum* feeds readily on snakes, tortoises, lizards, rhinoceros, buffalo, and more rarely on the other large mammals and cattle. *R. appendiculatus* occurs commonly on horses, dogs, all game animals, goats, sheep, and cattle. *R. sanguineus* may be found on birds, hares, ant-bears, dogs, lions, on a few antelope, and on stock. *R. simus* prefers rodents and other small animals as hosts for larvae, but, as nymphae and adults, it infests dogs, birds, horses, pigs, goats, sheep, cattle, and numerous species of game and vermin. Larvae of *Ixodes*, *Hyalomma*, and *Amblyomma* are frequently taken off small birds, ground fowl, and hares, whereas the nymphae and adults are found on many bush game and wild animals in the high country and on the plains.

Most of the important species of ticks oviposit and moult on the ground in the tufted masses of grass, at the base of bushes, and in niches or hollows made in loose earth or sand. There are a few, like *H. leachi*, which prefer the debris and rubbish around a dog's kennel for development; or like *Argas persicus*, which hides itself in cracks or fissures in the ground or among timber and under any structure that provides dark shelter. *H. leachi* may penetrate into rats' nests deep in the ground, where specimens in all stages of development have been collected. *R. sanguineus* behaves very differently in houses. The replete tick drops off a dog and often crawls up walls to seek shelter in the framework of wooden houses, behind cornices or immediately above the ceilings. The female lays her eggs in these situations, and engorged larvae and nymphae moult there. The writer has seen, several times, numerous ticks emerging from these hiding-places, spreading over the walls of a living-room or forming a live column marching, as it were, directly towards a corner where the house-dog habitually rests and sleeps. In the case of *Hyalomma* species, the adults are extremely active. When a person or an animal rests on the ground in infested areas, the ticks can often be seen hurrying from all directions to the likely host. It is interesting, too, to watch *R. pulchellus* adults poised on blades of grass ready to cling to an animal that passes within range of its extended fore-legs; or to observe a brown cluster of larvae at the tips of grasses.

The life-histories are of the three-host type in the majority of ticks belonging to *Rhipicephalus*, *Amblyomma*, *Haemaphysalis*, *Ixodes*, and *Aponomma*. A larva which hatches from an egg gains access to a host, feeds to repletion, drops to the ground and moults. The nympha which emerges from the moult seeks another animal on which to feed. When engorged with blood, it leaves the animal, drops to the ground, where it moults to produce an adult. The male or female adult must now find a third host. The female will swell out with blood and then drop off to

lay her eggs and die. The male may remain on the animal for several weeks; he will feed more than once, but will not distend like the female.

B. annulatus decoloratus is a one-host tick. The larva feeds on a beast, moults after engorging and, as a nympha, attaches once again near the original spot. When the nympha is replete with blood, it casts its skin as the larva did, without leaving the host. The resultant adults feed on the same animal and, in due course, the female drops to the ground to oviposit.

R. bursa and *R. evertsi* are two-host ticks. In these cases again, the larva feeds and develops into a nympha on the host. The fully-fed nympha, however, drops off and, after ecdysis, the adult that emerges has to find a second host. As in the previous instances, the female engorges and falls to the ground to lay eggs.

All the known East African species of *Hyalomma* are either three-host ticks or they may be partially three-host ticks. A brood of larvae fed on a rodent will feed and drop off first as a batch of engorged larvae; another lot of the same brood, put on the rodent at the same time, will feed and moult to nymphae without dropping off; the engorged nymphae, however, will always leave the host to moult on the ground. The nymphae from the engorged larvae which dropped have to reach another host; they will again fall off as engorged nymphae and undergo ecdysis. The adults, of course, require, in this case, a third host. When larvae of *Hyalomma* are fed on cattle, sheep, or poultry, they drop as engorged larvae and the life-history is continued as a three-host type.

The larva of *A. persicus* is the only instar of that species which attaches itself to its avian host for several days. It feeds for 5 or more days, falls off and develops into a first nympha. The tick, from now on, feeds only for about 1 or 2 hours at a time; and preferably at night or in the dark. The first nympha feeds for this short period, leaves its host and, in a fortnight or so, casts its skin to emerge as a second nympha. It again takes a meal and creeps away to develop into an adult. The female feeds at intervals between which she deposits her batch of eggs in sheltered places. The *Argas* species differ from those already mentioned in that they have two or more nymphal instars, in their manner of feeding and in the intermittent way the female lays her eggs.

The development of *Ornithodoros* species is still different. *O. megnini* may be classified as a one-host tick. The larva feeds deep inside the ears; it moults to a nympha on the host. The replete nympha falls off and develops into an adult which, if a female, lays her eggs after fertilization. Neither the male nor the female is normally found on animals, for the nympha has acquired sufficient food to sustain the adults in their main function in life. Incidentally, the nympha usually remains on the host for about a week to a few days over a month; but it may remain attached for several months—even up to 7 months.

O. moubata presents yet another kind of life-history. The female lays her eggs in batches. The larvae that hatch out are unable to feed. After a short period of quiescence, they develop into nymphae. These feed at intervals; and between each meal, lasting from 15 minutes to over 2 hours, they undergo ecdysis. The male nymphae moult from 3

to 5 times, the female nymphae from 3 to 7 times, before developing into adults. *O. moubata*, therefore, is an intermittent feeder and attacks a host for short periods only.

There are other aspects of tick-life that need closer attention. For instance, larvae of *Hyalomma* will feed very indifferently on hares, cattle, and sheep for the most part of a year. Yet, at other times, they will feed readily and drop off in large numbers. This peculiarity cannot always be accounted for by an acquired immunity on the part of the host. Heavy infestation of hares by *Hyalomma* larvae is frequently followed by the death of the host. It has also been observed that females of *R. appendiculatus* will engorge on experimental animals and, for some unaccountable reason, a varying percentage fails to oviposit and dies while others of the same batch will reproduce normally. Such species as *R. pulchellus*, *A. variegatum*, and *A. gemma* collected in the field will, at times, oviposit, hatch, and feed well; at others, and under identical conditions, they fail. Another illustration is of the morphological changes, not only in size, but in superficial characters of ticks of one species collected from different localities. *R. capensis* shows a very wide range of variations whilst *R. appendiculatus* may often be difficult to recognize.

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MIXED FARMING IN NORTHERN NIGERIA

Pt. I. ORIGIN AND PRESENT CONDITIONS

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WITH PLATES 3, 4, 5, 6, 7.

1. Introduction

This account is the result of a visit to Northern Nigeria to study mixed farming, which has been in existence there for sixteen years. It was made possible by the generosity of the Trustees of the Carnegie Corporation.

The term mixed farming has been applied in Nigeria to the introduction of a definite system of animal husbandry into the agriculture of that country [1]. It represents a fundamental agricultural revolution in which a system of stock management has been grafted on to the indigenous shifting-cultivation methods, thus creating a continuous form of cultivation. It involves a mixing of the animal husbandry of the nomadic Fulani herdsman with the cultivation of the soil by the Hausa peasant, and has given rise to a system of permanent farming whereby a man with cattle of his own, say two working oxen and a few cows, can plough and maintain in fertility an area of land sufficient to supply all the requirements of himself and his family, and to obtain a surplus balance as a return for his labour and for his extra capital expenditure.

Thus mixed farming represents a gradual evolution from the shifting methods of cultivation to a static type of agriculture, by the introduction of animal husbandry and with the use of animal cultivation.

Lynn [2] very clearly describes the difference in farming terminology in England and Africa, and shows why cattle farming has not been a custom of the latter country. In England the term 'mixed farm' is generally applied to a farm consisting of both grass and arable fields: the idea of any kind of farm without live stock is never considered, for such a farm does not exist. In West Africa, on the other hand, the word 'farm' is used almost exclusively to mean an arable field or orchard. It is but comparatively recently that the Governments of Nigeria and the Gold Coast have come to recognize the connexion between agriculture and live stock [3]. The reason for this is not hard to find when it is remembered that European penetration came from the sea, and for many years practically all agricultural exports came from the forest belt where conditions were not suited to live stock. In the savannah country beyond the forest, where live stock were found, outbreaks of epidemic diseases, of which rinderpest in cattle was the most serious, made stock-rearing a hazardous enterprise and not a suitable basis for a settled form of agriculture.

The success of the Government's policy of immunization of cattle against rinderpest carried out by the Department of Animal Health, together with the development of road and rail transport, have altered

the whole situation. Not only can live stock now form the basis of a settled system of agriculture in savannah country but they probably represent the only way in which the lot of the country peasant can be improved [2].

2. History and Evolution of Mixed Farming

Shifting cultivation was originally the most commonly practised method of raising crops, the land being farmed for several years until it became exhausted; it was then allowed to return to fallow under bush and grasses for a period of years in order to regain fertility. This system was evolved by the most primitive cultivators, possessing the minimum of equipment, i.e. a hand hoe, and is only capable of continuance where land is abundant. It is a wasteful system requiring a considerable area of land per family, and, where pressure on the land occurs through increase in population, it invariably has to give way to more intensive methods.

As a natural corollary, other systems of mixed cropping were gradually evolved as it was found that by such means the land could be kept for longer periods under cultivation. In areas nearer to large towns, where great pressure on the land existed, more intensive systems of agriculture were forced on the people, and gave rise to continuous or permanent cultivation.

Permanent, in contrast to shifting, cultivation, is the method followed in all countries of the world except the most primitive, the fundamental principle being the maintenance of soil fertility by the use of manure. It is found in Northern Nigeria around the big cities and large towns wherever manure is available, for it has been the practice of farmers near large towns and villages to purchase night-soil and to cart it out to their farms.

In Southern Nigeria, in the forest country, where the rainfall is high and there are no cattle, it was found that the decomposition of vegetable matter, dug into the soil, also maintained soil fertility, whereas in Northern Nigeria, in the savannah country with a lower rainfall, green manuring was unknown, as manure was available from the Fulani's stock. For many generations the natives of Northern Nigeria have realized that the use of animal excreta and compound sweepings helped to produce better crops, and that if applied at regular intervals permanent cultivation of the land would be possible. It has been customary for the Hausa peasant to encourage the nomadic herdsman to graze over his arable land after harvest, and to 'kraal' his cattle there by night, in return for a payment in corn. The making of farmyard manure, by the enclosing of animals on bedding of grass or the roughage of cultivated crops was, however, unknown and, with the increased cultivation of economic crops, it was evident that these two known systems would have to be combined to maintain soil fertility.

By almost continuous cropping under the pressure of an increasing population, soil fertility in certain parts of the northern provinces was being greatly reduced, and only poor crop returns were being secured. The competition of economic crops, such as cotton and groundnuts,

with the requirements of the food crops was becoming marked, and it was evident that a more balanced form of agriculture had to be evolved if satisfactory social advancement was to be secured [1]. To this problem in particular the Department of Agriculture has devoted its attention during the past sixteen years.

It was soon realized, after preliminary investigations had been carried out, that no permanent improvement was likely to be secured in native agriculture unless some form of animal husbandry could be effected. It was also realized that the introduction of the plough was an invaluable adjunct to animal husbandry, but that, unless its introduction was accompanied by a sound system for the maintenance of soil fertility, soil exploitation and erosion would result, giving rise ultimately to a situation far worse than under existing conditions. This decision meant that extensive investigations into every aspect of mixed farming would be necessary before some simple systems were evolved for introduction to the farmers. Experimental stations were established at Samaru, Kano, and Ilorin in order to test, by experiment, the various methods of cultivation of food and economic cash crops, the rotation of crops, and different systems of manuring. Live-stock problems likewise received attention. Examination of the relative values of different breeds of stock, for the needs of the farms both for work and for milk, the evolution and testing of farm implements, the training of animals for work, the study of the feeding of animals under the conditions of native farms, and the manufacture of farmyard manure were among the multifarious problems studied. Selected herds of cattle were established at Samaru and Kano, and special live-stock farms at Shika and Ilorin. Implement factories for the manufacture of wooden ploughs and small, iron-toothed cultivators were likewise started. Agricultural Officers and specialists (including botanists, chemists, and live-stock officers) all worked on the subject, and it was only after adequate information had been obtained to indicate the directions in which improvements could be effected in the existing agricultural methods that attempts were made to translate the new methods into practice by the establishment of farm centres and demonstration farms.

As the result of this work, over a period of four years, a system of mixed farming was evolved at Samaru, but it was not until 1930, after six years' work, that mixed farming was considered proved beyond this experimental stage. It is upon the basis of this original Samaru system that the extension of mixed farming has been made to suit the varying conditions of Northern Nigeria.

3. Present Conditions

Although the general principles of mixed farming are the same everywhere, the details of the best system for any given area must depend upon the particular conditions in that area [2]. From the original system evolved at Samaru mixed farming has been extended to suit the varying conditions of Northern Nigeria. It is now being considered or introduced under five sets of conditions.

(1) In the Zaria Province, and parts of Sokotu, Katsina, and Katno,

where the native system of agriculture is based upon shifting cultivation, and where people live mainly in villages or hamlets.

(2) Around Kano and other big cities, where people live close together in isolated compounds or hamlets, and farm continuously the land between them.

(3) In the far north of the Sokotu Province where conditions are so severe and the land is so poor that mixed farming with cattle is uneconomic; systems based on the management of donkeys and goats are being tried out.

(4) In the Sokotu Province where rice-growing forms the basis of farming.

(5) In the Ilorin Province, 'the Middle Belt', where people live in villages and trypanosomiasis precludes the success of a system based on the Zebu cattle.

Most progress in the extension of mixed farming has been made under the Zaria conditions, where shifting cultivation is practised and where there is adequate room for expansion.

(1) *Mixed Farming under Zaria Conditions* [2]

It was found that a man and his family using a plough, a cultivator, and two working bullocks could farm an area of from 10 to 12 acres instead of only 2½ to 3 acres as he did before by hand methods. Provided that attention was paid to feeding and the provision of bedding for the bullocks and other stock, this area could be maintained in a high state of fertility. All waste products from the farm must be carefully conserved for use either as fodder or as bedding material. The ideal is to feed the animals on the farm as much as possible, so that the dung and urine are not lost; a certain amount of bush grazing, however, is generally necessary.

Fodder.—Guinea-corn leaves, groundnut and cowpea tops, and bush grazing form the basis of the maintenance ration for a bullock or a cow; and guinea-corn bran, guinea corn, and cotton seed the basis of the production ration. *Mucuna* hay and sweet potatoes, both tops and tubers, are valuable supplementary feeds.

Manure.—Guinea-corn and millet stalks, weeds, and any bush grass too coarse for feeding are used as bedding and trampled into manure under the feet of the stock. The output of manure made in this way has been found to be about 5 tons a year from a pair of bullocks. Experiment has shown that soils in Northern Nigeria respond very well to what, in temperate countries, would be considered negligible quantities of manure [4].

An application of 2 tons of farmyard manure per acre results in an increase in the yield of guinea corn of up to 100 per cent.; the success of the system hinges upon this point. A mixed farmer with the manure from his bullocks and other stock can dress from one-quarter to one-third of his farm each year at the rate of 2 tons per acre.

(2) *Mixed Farming under Kano Conditions*

Where the population is dense and the native system of cultivation is continuous, as around Kano and other big cities, some modification in

the original system evolved at Zaria is necessary. Progress under these conditions has not been so rapid. Since the area of land available for cultivation is limited, the success of the mixed farming here must depend upon the greater intensification of crop production by heavier manuring and more efficient cultivation, instead of by an extension of the area cultivated. By contrast with Zaria, conditions demand an intensive system, and high yield per acre is important [2].

Early experiments in mixed farming on a communal basis in the Bichi Colony were not a success [5]. The failure was due to misunderstandings and to unsuitable people, such as retainers of the local District Head, working the scheme. Interesting experiments are now in progress on the Kano Experimental Station: the first is with a dairy farm and the second with a donkey-and-goat mixed farm.

Dairy Farm.—Two small holdings of 2 to 2¼ acres are farmed together. Each is worked by a man and his family and stocked with a cow, a donkey, and a few goats, and the stock is kept permanently on bedding to make the maximum quantity of manure. The cultivation of the two farms is done communally with the two cows, and since there are only 4½ acres and the soil is suitable this is no hardship to them.

Mr. Faulkner, late Director of Agriculture, Nigeria, said when discussing the Kano suburban areas: 'When the effect of manure is relatively so great, while at the same time most farmers' crops are far below the maximum owing to the lack of manure, it is clearly within the bounds of possibility, however paradoxical it may seem, that the way to make the land feed two men where it fed one before is to make it first feed one cow where it fed none before' [2, 5].

Donkey-and-goat farm.—The second experiment, which has now been going on for the last three years, is with a 5-acre farm stocked with three donkeys and ten adult goats. The stock is kept in an enclosure to prevent damage to the crops and to make the maximum quantity of manure. Results have shown that the donkeys have quite successfully carried out all the cultivation of the farm, and fertility has been maintained by the manure produced by the goats and donkeys, whilst the goats have in addition provided both milk and skins. The quantity of manure produced is from 3 to 4 tons from the donkeys and from 2 to 2½ tons from the goats; five goats are equivalent to one donkey, which can produce about 1 ton of manure per annum.

(3) *Mixed Farming in the Far North of the Sokotu Province, Donkey-and-Goat Mixed Farms*

In the drier and more remote parts of Sokotu and Bernin Kebbi the Zaria system of mixed farming is not suitable. The soil is so light and so poor that it is neither possible to grow cotton nor to obtain anything but the poorest yields of groundnuts. The best yield obtained in Sokotu on well-manured land was 654 lb. per acre, but the average is only from 350 to 400 lb. per acre. In these areas, therefore, the farmers have no direct export crop, so that, even if they were provided with a minimum advance with which to buy cattle and implements, they would have great difficulty in finding money to repay the loan. Another reason for

the unsuitability of the Zaria system is that unless a farmer can keep other stock for the production of manure, the use of bullocks for ploughing is not economic, for on these light soils a pair of bullocks can easily cultivate some 20 acres, whereas the manure produced is only adequate for 2 to 3 acres. Moreover, on such soils comparatively heavy dressings are required. The only solution appeared to be either to increase the number of cows kept by each farmer, or to try to make more use of goats as both manure-makers and as a source of revenue.

Comprehensive experiments are now in progress to study the possibilities of various mixed-farming methods, and to study the economics of goat-keeping, together with the husbandry of donkeys and goats. These include the following experimental farms of 10 acres each:

1. Mixed farms with donkeys and goats in areas where ample bush grazing is available.
2. Mixed farming with donkeys and goats in densely populated areas where no bush grazing is available.
3. Permanent agriculture with hand cultivation with goats as manure-makers.
4. Mixed farming with cows with progeny as manure-makers.
5. Mixed farming with cattle and goats as manure-makers.
6. Mixed farming with a troop of donkeys.

(4) *Mixed Farming in Rice Areas of the Sokotu Province*

Experiments at the Kwore Irrigation Farm over a series of years have shown that the making of profit out of the irrigated land there depends entirely on the use of bullocks for the puddling of the rice fields. It has also been ascertained that on land under controlled irrigation, and with the use of oxen for puddling, yields of up to 4,000 lb. of paddy could be obtained, as against a few hundred lb. per acre which are usually harvested by the ordinary farmer [6].

Interesting experiments incorporating mixed-farming ideals are now in operation. Three farmers are growing rice under the improved system with the use of cattle. The areas of the farms are $2\frac{3}{8}$, 3, and 4 acres respectively; rice is grown under irrigation during the wet season, and crops such as sweet potatoes, cassava, maize, wheat, or groundnuts are grown on the manured land in the dry season. Returns from these farms prove conclusively that a man with three acres under irrigation with a pair of bullocks can obtain £7 to £8 per annum if he gets even an average yield, but he should get considerably more if he harvests what is now considered a good average return, i.e. 3,500–4,400 lb. per acre.

(5) *Mixed Farming in the Ilorin Province, 'Middle Belt'*

Experiments are being made at Ilorin to find a system of mixed farming suited to the Middle Belt. The main difficulty here is tsetse fly, which precludes the possibility of success of the Zaria system, which is based on the Zebu type of cattle. Dwarf pagan cattle (Maturu) found in the area are too small for work, but they have a very high resistance to

the local trypanosome. Crosses between these dwarf pagan cattle and the Zebu have not proved satisfactory, for, although producing an animal big enough for work, they do not thrive and sooner or later die from trypanosomiasis; they die sooner in direct proportion to the amount of Zebu blood in the cross [2].

The whole aspect of the mixed-farming work was changed, however, with the successful introduction of the humpless, so-called 'West African Shorthorn', from the Gold Coast [7]. These cattle are on the average 6–7 in. taller than the pagan cattle [7] and possess a superior conformation. Moreover, they appear to possess the same high degree of resistance to the local trypanosome as the pagan cattle. After two years at Ilorin the Gold Coast cattle are thriving and the bulls are working slowly but very steadily and willingly [8]. A scheme has now been started for laying down foundation herds of West African Shorthorns, and, with the assistance of the Colonial Development Fund, for carrying out experiments with this type of stock from the Gold Coast, Gambia, and French Guinea. It is proposed to keep the herds pure, and to breed up and improve the local Kaima and Muturu herds by using Gold Coast bulls, with a view to supplying the progeny to mixed farmers.

The importance of the scheme cannot be exaggerated; if it is successful the results will be undoubtedly applicable to many parts of the southern provinces where the need for animal products and manure is very great. Farmyard manure has been proved, even on the poorest soils, to give striking results, and if it was available in quantity it would solve the problem of soil fertility [8]. A great deal of experimental work remains to be done; a system based on the production of foodstuffs for the southern markets is under trial, and is giving promising results.

4. Progress of Mixed Farming

The following table shows the rate of progress which is being made, and the results obtained by the introduction and extension of mixed farming from 1928 up to December 1937.

Extension of Mixed Farming

Year	*No. started during year*	*Failure during year**	*Total No.*
1928	3	..	3
1929	9	5	7
1930	13	3	17
1931	31	4	44
1932	71	7	108
1933	84	19	173
1934	139	14	298
1935	348	25	621
1936	473	41	1,053
1937	454	60	1,447

* 'Failures' include all farmers who gave up the system for any cause, including death, when the heir was not capable or willing to continue the system.

In 1937 the percentage distribution of mixed farmers in the various Emirates included: Zaria 30, Katsina 22·7, Kano 17·7, Daura 11·8, Sokoto 8·36, others 9·4.

The practice of mixed farming has thus been rising rapidly and, in view of the very low prices of commodities like groundnuts and cotton, the figures can be regarded as satisfactory. The notable increase in the number of 'failures' in 1936 and 1937 is in part due to the additional numbers, for it is impossible to give the same personal attention to individual farmers as formerly. It would be a waste of time for the agricultural staff to persevere with men who make little or no attempt to act on advice, especially as other farmers are waiting to be set up. A strong line has been taken, therefore, and farmers who do not carry out instructions after repeated warnings are wound up and their cattle and implements sold to new farmers. Progress should not be measured entirely by numbers [8]. It is the total number of peasant mixed farmers in any particular area which is the index of progress [7]. Satisfactory progress during the last three seasons has been made in the number of peasant farmers; these have increased from 252 in 1935, 475 in 1936, to 739 at the end of 1937, and extension has been most rapid in areas where there is plenty of land available, and the natives follow the methods of shifting cultivation, i.e. in Zaria (423), and in Katsina (329).

The early stages of extension work were difficult in every district and it is interesting to note that almost invariably the political heads of the people led the way. It was found also, as might be expected, that good hand farmers usually make good mixed farmers, but that the best men in a district do not come forward in the beginning; they watch developments and, when convinced, ask to be set up. It is these good farmers who, when once established, form the best demonstrators of the system. The main reasons for the popularity and consequent increase in mixed farming can be summarized as follows:

1. Under the Zaria system a man can deal more easily with a larger area under cultivation.
2. Greater returns are obtained both in total production and in yields per acre, which result in an improvement in the families' conditions.

At Maigana, investigations over a period of six years show that the yields per acre of mixed farmers are considerably higher than those of the hand farmers:

Crop	*Farmers*	*Mixed farmers*
Sorghums . . .	652 lb.	779 lb.
Millet	348	490
Groundnut (kernels) . .	320	455
Cotton	129	286

This increase can be attributed not only to the use of manure but also to the effects of better cultivation. Figures also show that the average return per acre of a mixed farmer is 16*s.* 9*d.* as compared with 13*s.* 3*d.* for a hand farmer.

5. Organization of Agricultural Department for Mixed-Farming Extension Work [2]

For the extension of the results of the farming experiments carried out at experimental stations and on stock farms the organization of the Agricultural Department consists of: (A) farm centres; (B) demonstration farms; (C) extension mallams (overseers); and (D) cattle boys. This organization is paid for entirely by the Native Administrations concerned, and the cost of the salary and expenses of the Agricultural Officers in charge is shared equally between Government and the Native Administration [5].

A. *Farm centres.*—A farm centre usually occupies an area of from 40 to 60 acres and serves a radius of 30 or 40 miles. It comprises the following:

1. One or more demonstration farm units, run by a paid labourer and his family. (These are discussed below.)
2. Provision for simple experiments on 10 to 20 acres; seed-testing and bulking, manurial and spacing trials, &c.
3. Fodder farm for feeding the cattle in the cattle-pool before distribution to farmers.
4. A training ground for new mixed farmers and cattle.
5. Facilities for treating simple ailments of mixed farmers' cattle; injections for trypanosomiasis, treatment for streptothricosis, calf scour, and so on.
6. Grade bull at stud.
7. Demonstration of improved water-lifts from wells and small-scale irrigation.
8. Milk recording and hand-rearing of calves.
9. Implement factory for the manufacture and repair of ploughs, cultivators, yokes, &c.

B. *Demonstration farms.*—Demonstration farms are complementary to the farm centre. They usually serve a radius of about ten miles, and are situated upon roads to markets and in accessible places where new mixed farmers can go for advice. Each farm consists of a unit area—8 to 12 acres—worked by a labourer and his family with a pair of bullocks and a plough. An essential feature of the demonstration farm is that it should resemble a native holding as much as possible [9], and be managed with the minimum amount of supervision. Thus all buildings are of simple native construction, and nothing is demonstrated which could not be copied by a good mixed farmer. In order that control may be complete it has been found necessary to have a paid labourer in charge of the unit. The capital cost of establishing a demonstration farm is about £15, and a similar sum is required annually to run it. Receipts from the sale of produce—paid into Native Administration as revenue—frequently pay for the annual cost, especially if the stock includes a cow.

Cropping and live-stock management follow the simple methods already described in the Zaria system. Costs are very carefully kept upon demonstration farms: the farms are considered always as economic units. On principle no experiments are ever attempted; only practices

tried and proved upon experimental stations or farm centres are demonstrated. Thus the demonstration farm represents an essential link in the extension of experimental results; this is particularly true in the early days of establishing this system in a district. After a few years, successful mixed farmers themselves provide the best demonstration; but for many years to come there will always be some improvement to be demonstrated.

C. *Extension mallams.*—An extension mallam (*mallam* is Hausa for teacher or scribe) is stationed in each mixed-farming district as an itinerant instructor. He is usually a man who has attained a comparatively high standard of education at the Katsina Higher College, or some similar school, and spent two years at the Department of Agriculture's farm school at Samaru. Before going out into the district the mallam works at a farm centre for a year to make certain that his outlook upon native agriculture is desirable, for it is very necessary that he should be in complete sympathy with the farmers with whom he is dealing in order that he may have their confidence. The mallams are Native Administration officials and frequently they have obtained their training at the farm school with a Native Administration scholarship.

The duties of an extension mallam are to supervise the labourer on the demonstration farm, to receive the names of those who wish to take up mixed farming, and to assist those already established. This last function is most important, and in order to assist men who need help the mallam follows a definite itinerary every week, so that farmers will know where the mallam is to be found on any given day. The mallams have been taught by the Animal Health Department to give injections for trypanosomiasis. They also attend at markets to see that farmers get a fair price for their produce.

D. *Cattle boys.*—A number of 'cattle boys' work under each extension mallam. They are generally labourers who have shown themselves trustworthy, and their function is mainly to assist first-year mixed farmers in the practical details of the new system, yoking of bullocks, hours of working bullocks and feeding, adjustment of ploughs, supply of bedding, and so on.

6. Working Details of Mixed-Farming Extension Work [2]

1. *The supply of cattle.*—All the cattle in Northern Nigeria are of the Zebu type, of which there are a number of distinct breeds, White Fulani, Godali, Adar, and Rahaji being the most important. White Fulani have been found best for milk and work; Godali and Adar are considered only slightly inferior to White Fulani. The brown Shuwa cattle from Borneo are rather light for work but the cows are good milkers. The brown long-horned Rahaji are found to be quite worthless for work, so their milking capacity is immaterial. Since the farmers have no cattle of their own it is necessary for the Agricultural Department to supply them. A few bulls are available from Government's stock-farms but the main source of supply is the Fulani herds.

Suitable animals are purchased by Agricultural Officers with money advanced for the purpose by the Native Administration. The cattle are

numbered by branding on the horns as they come into what is known as the Cattle-pool. A Cattle Purchase Book is kept, into which the number of each animal is entered with its purchase price as it comes in, and the name of the farmer to whom it is eventually distributed. Animals not previously immunized against rinderpest are sent to a veterinary camp for inoculation. Cattle-pools are maintained at Farm Centres; here the animals are trained to work, bulls as well as bullocks, and farmers can come to learn how to handle their animals before taking them over.

With only a few farmers to set up each year the supply and management of the animals required presented no great difficulty, but now, as the number of farmers requiring cattle runs into hundreds each year in some places, the supply of cattle presents a very big problem. Not only is there this difficulty of supply but also the risk of disease to be considered, with strange cattle coming in all the time. It has been found necessary to erect cattle dips at some centres and to dip all cattle regularly once a week.

The cost of a working bullock varies from £2. 10*s*. a head upwards; thus the minimum capital required to be invested in live stock to start mixed farming is about £5.

In the years 1936–7 prices of cattle rose rapidly owing to the increased demand of the meat market in the southern provinces, and animals which were worth £1. 10*s*. the year before are now worth £2. 10*s*. to £3, and in some districts are difficult to obtain even at that price.

2. *The supply of implements.*—Much research was carried out before suitable implements were found. Attempts to work with ploughs had frequently been made before 1924, but met with no success, principally because the ploughs used were not suitable. Except in areas of low rainfall in the extreme north the native practice is to grow crops on ridges, but it was found that the biggest ridge that could be made by a two-bullock plough was from 2 ft. 6 in. to 3 ft., against a ridge of from 3 ft. 6 in. to 4 ft. or more made by the natives with hand hoes. Experiments were carried out to test effects of a similar ridge upon crop yields, and it was proved that, provided a suitable spacing was adopted between the plants on the ridge, the smaller ridges made by the two-bullock plough gave just as good a yield as the larger hand-made ridge. Small ridging-ploughs have therefore been adopted as standard; they have been found equally efficient under the dry conditions in Kano and northern Katsina as under the wetter conditions in Zaria. Single-furrow ploughs are practically never used, since for many years to come farmers will be able to afford only one plough, and the ridging-plough is by far the most useful and the easiest to work.

In the early days of mixed farming the prices of cotton and groundnuts were depressed, and it was essential to keep the farmer's capital outlay as small as possible. To accomplish this a wooden plough was made in the implement factories which could be sold for as little as 14*s*., as against over £3 for an imported iron plough. These ploughs served their purpose, and some are still in use on the light soils in northern Katsina. By comparison with the imported ploughs, however, the only

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thing in favour of the wooden plough is its price. The draught on the wooden plough is very heavy, it is not very effective in breaking new land or in splitting ridges, and it is easily damaged. The advantages of the iron plough were quickly appreciated by farmers, particularly those working the sticky soil around Zaria, and the iron plough has now superseded the wooden one in most districts.

The plough found most suitable up to the present is Ransome's DY ridging-plough. It is a strong little plough with adjustable mould-boards, and will make a ridge up to 2 ft. 9 in. wide. For working between the ridges the mould-boards can be removed entirely if desired; this is especially useful for working-in groundnuts. The possibility of improvements in the plough is not being neglected; experiments with differently shaped mould-boards are being carried out by the manager of the Empire Cotton Growing Corporation's seed farm at Daudawa, and these are being closely followed.

In conjunction with the plough some sort of cultivator is required to work between the ridges, and in some cases to break the surface of the soil in front of the plough. Two types of cultivator are made in the implement factories; both are cheap and satisfactory for the work for which they were designed. The first is a three-tine cultivator with a wooden frame, the second a five-tine cultivator with an iron frame. The tines are made by native blacksmiths out of bar iron (mild steel) $2\frac{3}{8}$ in. wide and $\frac{3}{4}$ in. thick. The wooden frame is made of logs of 'mariki' (*Anogeissus leiocarpus*) or 'kanya' (*Diospyros mespiliformis*), nailed together in the shape of a cross, with an iron drag-link at the end of the longest limb, and a single stick (*Terminalia* spp. or *Acacia* spp.) fitted into a square hole at the other end for a handle. The tines are held rigid in the mortise by metal wedges. The wooden cultivator can be sold for 4*s.* to 7*s.* 6*d.*, depending upon the cost of materials and workmanship in different districts.

The iron cultivator is rather more elaborate; it is made entirely of iron, except for the wooden grips on the handles, and can be sold for 14*s.* 6*d.* The five tines are held on by clamps to a simple triangular-shaped frame made of flat bar iron. The spanner supplied with the DY plough fits the nuts on the clamps. Two iron handles are held in place with the clamps holding the two back tines, and they are made rigid with a brace of $\frac{1}{2}$-in. rod iron. A drag-link to take the chain is fitted in front.

Double yokes are most commonly used; they are made at the implement factories and sold for 1*s.* 6*d.* each. The yoke consists of a single bar, generally a branch of 'doka' (*Isoberlinia doka*), fitted with short wooden neck-pieces. Two sets of holes are made to take the neck-pieces, to alter the position of the bullocks for working between the ridges or for splitting ridges. An iron staple is fixed to the middle of the yoke to take the chain or pole from the plough or cultivators.

The minimum dead stock required by a mixed farmer consists of a plough, a cultivator, a trek chain, a yoke, and rope for reins, and the cost varies from as little as 28*s.* up to £4, according to the implements desired. One or two mixed farmers require a cart; a simple box-body

on a pair of iron wheels can be sold for about £8. This expense is justified, however, only when outside contracting work is available; it is not justified for carrying manure alone on the average farm. For this purpose two large leather bags placed pannier-wise on a bullock's back are being used successfully at Maigana, whilst at Daudawa mixed farmers are using a simple wooden sledge for the purpose.

It is interesting to note the comparative amounts required to establish a mixed farmer in the years 1930 and 1936–7:

	1930			1936–37		
	£	s.	d.	£	s.	d.
Cattle, 2 working beasts	4	0	0	6	8	0
Plough (wooden)		13	0	(iron) 3	7	0
Chain		7	0		7	0
Cultivator (wooden)		5	0		5	0
Yoke		1	6		1	6
Rakes		1	0		1	0
Average advance	£5. 10s.–£6.			£10. 10s.–£12. 10s.		

3. *Loans to farmers.*—It is clear from the above figures that the extra amount of capital required by a farmer wishing to take up mixed farming varies from £7 to £12. 10s. at the present level of prices. Very few hand farmers are in a position to put down such a sum. A hire-purchase scheme is therefore an essential part of the machinery for the extension of mixed farming. This is now provided by the Native Administrations, and considerable sums of money are voted to the Agricultural Department for the purchase of animals and implements. The money is spent by the Agricultural Officers in their capacity as advisers to the Emirs. In the Zaria and Kano Provinces the Native Treasuries have advanced £3,500 each for their respective schemes.

4. *Accounting.*—A deposit varying from 5*s.* to 30*s.* is required from the farmer, depending on the implements desired and the district. It is desirable that at least 20*s.* be deposited if an iron plough is purchased. The amount is credited to an account opened for him in the Farmers' Ledger. As soon as possible trained bullocks and implements are issued to him and their value is debited to his ledger account; the Cattle Pool Account and Implement Accounts are correspondingly credited.

Interest is charged at the rate of 5 per cent. per annum on all outstanding accounts on April 1 each year, but since the idea of interest is not compatible with Koranic Law it is known as 'hiring charge'; the money obtained from hiring charges is not repaid into the Native Treasuries each year; it is set aside and carried forward to form an insurance fund for the scheme, as a safeguard against loss, and to provide a means of assisting mixed farmers who have sustained losses in their stock through no fault of their own.

All books connected with the scheme are kept by the Agricultural Officers, and a monthly list of repayments due is submitted to the District Officer. The money is then collected by the Native Administrations and its collection is regarded in exactly the same way as the collection of tax.

One unavoidable feature of the system is that it involves an enormous

amount of work in connexion with the accounts. In several of the Emirates there has been a rapid rise in the number of new farmers, and the accounts now occupy a great deal of the time of the Agricultural Officers which should preferably be spent on purely agricultural work [8].

5. *Tax.*—Until a mixed farmer has repaid his advance his tax-assessment remains at what it was the year before he adopted mixed farming. Also he pays no cattle tax 'Jangali' upon his working oxen. 'Jangali' is paid at the rate of 1*s.* 6*d.* per animal per annum.

6. *Establishing a mixed farmer.*—A native wishing to become a mixed farmer applies to the Agricultural Department at the end of the rains, and provided he is a bona-fide farmer of good character recommended by his village headman his farm is inspected. If his farm is near to water, has fly-free grazing, and has sufficient land available for expansion to the optimum size, an advance is given and the deposit mentioned above is paid. If cattle are to be supplied a covered pen has to be erected for the manufacture of manure, and all by-products of the farm must be collected for the provision of fodder and bedding for the stock.

If the above conditions are agreed to, he can then come to the farm centre to choose and train his cattle, to learn how to look after them, and to be taught how to use and maintain his implements efficiently.

In the early stages of his life as a mixed farmer he has to be constantly advised in the management and working of his stock, as there is a tendency at first to neglect the feeding and bedding, and to overwork the animals. He is not encouraged to increase his acreage to any extent and is advised to start in a small way. To get him to make and use pen-manure is the first big step upon which the entire system is based. Once he has taken to this and has proved its value to his own satisfaction, his confidence will be gained and the way is clear to the introduction of further improvements.

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FIG. 1. Fulani cattle kraaling, i.e. manuring Hausa man's farm

FIG. 2. All crop residues are carefully preserved and are used as cattle fodder. The leaves of maize, millet, and sorghums are stripped off the stems and used as feeding

FIG. 3. Kano Province. Very simple cattle-pens for manure-making

FIG. 4. Donkey and goat farm, Kano. Inside the enclosure: stock stamping-yard in foreground, farmer's house on left, manure-pen on right

FIG. 5. Gusau Sokoto. A typical mixed farm, showing large grain stores which are filled from the top

FIG. 6. The cattle-pen and house of a mixed farmer at Daudawa; note simple construction

FIG. 7. Kafinsoli Farm Centre, Katsina. A typical Native Administration farm at farm centre. Note recent cattle-pen and method of stocking crop-residues

FIG. 8. Maigana Farm Centre, Zaria. Cattle-pen on demonstration farm. Simplicity emphasized, left section for dairy cow, centre for calves, right portion for working animals. Suitable for non-game country

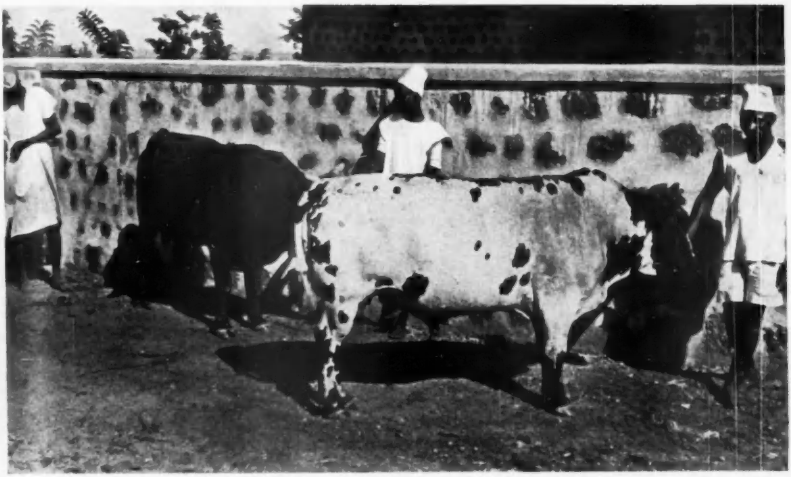

FIG. 9. Ilorin Stock Farm. West African shorthorn bulls from Gold Coast. Height 43 in. to withers

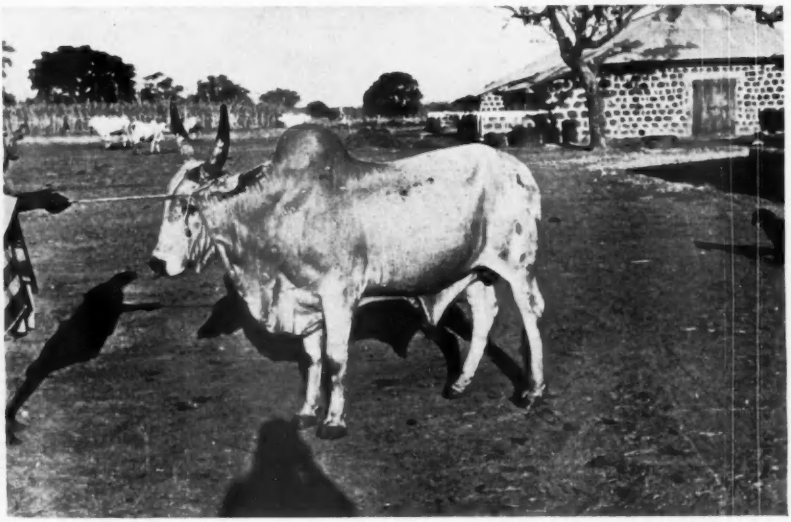

FIG. 10. Shika Stock Farm, Zaria, Zebu stud bull. A large well-formed beast, and a very good example of the White Fulani Zebu cattle

MIXED FARMING IN NORTHERN NIGERIA

Pt. II. EDUCATION, LAND TENURE, AND FUTURE PROBLEMS

Pt. III. A BRIEF COMPARISON OF CONDITIONS IN NORTHERN NIGERIA AND TANGANYIKA

J. G. M. KING

(*Agricultural Officer, Tanganyika Territory*)

Pt. II. EDUCATION, LAND TENURE, AND FUTURE PROBLEMS

WITH PLATE 8

Agricultural Education

Staff.—As a natural adjunct to the successful introduction of mixed farming into native agriculture, an efficient native staff was essential. For the purpose of establishing this staff and for their training in improved agricultural methods, a farm school was established at Samaru. This school is staffed and maintained by Government and is run by the Agricultural Officer in charge of the Experimental Station, for the training of both Government assistants and for Native Administration mallams.

At first difficulty was experienced in getting the right type of pupil; this, however, has been overcome, as now most of them are drawn from the Katsina Higher College, and many hold scholarships given by the Native Administrations. At Samaru there are two main courses of instruction: (1) Senior assistants' course; (2) Junior course for mallams, Native Administration teachers, and the like. In addition, short refresher courses are given for extension mallams and interested agriculturists.

The senior assistants' course.—Pupils for this course receive a general education at Katsina Higher College up to Standard 6, after which they receive a year's course in specialized science, in order to give them an elementary scientific background. On the completion of this year's course they then attend a two-years' training course at Samaru. Here, their training is designed to give them a good all-round agricultural education, with a strong practical basis. In their first year at Samaru they receive instruction in book-keeping, botany, chemistry, economics, plant husbandry, in addition to practical work. The school farm is divided into three-acre mixed holdings, each of which is entirely managed by three pupils, so that one pupil is responsible for one acre during his residence. During the second year they receive lectures in animal husbandry, chemistry, plant pathology, entomology, and veterinary hygiene, whilst in addition to their farm work they receive subsidiary practical training in milking and herd management, elementary inoculation work, and undertake excursions and extension tours under experienced mallams.

During their last year at Katsina Higher College, and for the first year at Samaru School, the pupils receive a subsistence allowance from the Education Department of £2 10*s.* a month. At the beginning of the

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second year at Samaru they are appointed, if satisfactory, to the permanent establishment of the Agricultural Department as Junior Technical Assistants on a commencing salary of £36 to £54 per annum, according to merit.

The junior course.—This course is now designed to give a good practical training to departmental assistants, Native Administration mallams, or teachers who want a short course in agriculture. It is a three-months' course which is given during the cropping season and is mainly practical, as only one and a half hours of theoretical instruction are given per day. The theoretical work is confined to very short lectures on plant and animal husbandry, and plant and animal diseases. Each student is given a good practical agricultural note-book, and notes which are dictated are entered by themselves into their own books. The practical training includes three weeks' intensive instruction in:

1. Farm practices, ploughing, cultivation, &c.
2. Herd management, including calf-rearing and dietetics.
3. Work on the school farm, utilization of crop by-products, &c.
4. The extension work for mixed farming, including buying and training of cattle, systematic inspection, and routine work.

Courses for Administrative Officers.—Since mixed-farming extension work is very largely a function of the Native Administrations it is very desirable that the Administrative Officers should be conversant with the work of the Agricultural Department, and that there should be complete unanimity in agricultural outlook. To facilitate this an annual course lasting about a week is held at Samaru. These have proved highly successful and have been well attended.

School for mixed farmers at Kafinsoli, Katsina.[1]—In the Katsina Province at Kafinsoli, a Native Administration adult school for mixed farmers is in course of construction. The objects of this school are to train peasant farmers in general agriculture, and to provide facilities for them to run small mixed farms under close supervision. The main aim of the school is to turn out good peasant farmers, as opposed to the education of mallams; and the pupils will be young single or married men who are literate or illiterate, and who will come in for one complete cropping season.

It is proposed to start twelve mixed-farm units of eight acres each. These will be laid out in a similar way to the small demonstration farms, and will resemble native farms as closely as possible. Four pupils will run each farm so that one man will be responsible for 2 acres. By this means the pupils will be able to manage for themselves a holding on mixed-farming lines, yet have time for instruction in all other aspects of practical farming.

In addition, it has been suggested that the best twelve pupils be offered a second year's residence as a scholarship, and that they assist with the training of the three new men on each holding in the following year.

No school fees will be charged and, in addition to their keep, pupils will receive 3*d*. per week pocket-money. The produce of the farms will

[1] This school has very largely been sponsored by the Emir of Katsina, a keen educationalist, and it is he who decided on pocket-money allowances and the like.

either be sold, or be used towards defraying the maintenance costs of the school.

At the completion of the cropping season, i.e. 9 months, the school will be used as a training centre for extension mallams, thus enabling the teaching staff to be employed throughout the year.

Land Tenure

In Northern Nigeria a committee, appointed by the Secretary of State to inquire into the system of land tenure, established the fact that according to native customary law no private estate could exist and that all land was the property of the community. Land was granted to individuals who had the use and enjoyment of it, but, as this grant could at any time be revoked for particular reasons, freehold, as it is understood in England, could not be said to exist.

In order to prevent wholesale alienation of land under economic pressure, and the introduction of extraneous forms of land tenure, legislation was passed. In the Northern Provinces to-day all land is, by Ordinance, held in trust for the people by the Governor. Its disposition is under his control and no title to the use and occupation of any land is valid without his consent. Once a title has been granted, no transfer of possession or other dealing in land is of any effect until the transaction has received the Governor's consent [1].

In practice the land is allocated by the District or Village Headman acting in the capacity of the Emir's representative. A native farmer can obtain the right over the land in two ways: firstly by clearing it after having obtained permission to do so, and secondly by inheritance, subject to the approval of the original grantors. Thus a farmer wishing to obtain land approaches his village headman, obtains his consent, and commences to clear his farm.

The relation of land tenure to mixed farming is interesting. In areas near to large towns and villages, there is a tendency for mixed farmers to move right away in order to obtain their requirements in land. This move is undoubtedly accelerated by the fact that there exists a 'landlord class' who, while owning the right to the land, do not farm it themselves, but rent it in return for payment in corn. These 'landlords' are unwilling for their tenants to become mixed farmers owing to the risk of counter claims for compensation should they eventually wish to take over their farms.

In areas where there is adequate room for expansion, mixed farmers obtain extra land around their farms with no difficulty by applying for permission to the village headman. There is a tendency at first for a mixed farmer to cultivate too big an area. There are two main causes for this: (*a*) the genuine farmer who, through ignorance of the new system or over-zealousness, cultivates more than he can cope with efficiently, and (*b*) the genuine 'land grabber', who clears and plants large areas promiscuously in order to lay claim to the land near to his farm so as to keep out his neighbour. In the first case the difficulty can be overcome by education and instruction; in the latter case local public

opinion or the proposed taxation will remedy the evil. In the Zaria area a graduated tax on mixed farmers is under consideration, based on a holding of 12 acres. It is proposed that increases in taxation be paid on extra units of six acres by farmers employing labour, and allowances be made to farmers employing members of their families, in order to tax the capitalist farmer and to assist the family unit.

In Northern Nigeria, with the exception of a few experimental holdings which have not proved successful, there has been no attempt to introduce mixed farming with land settlement. Mixed farming has been introduced into native agriculture by using the existing indigenous organization.

Future Problems

Many problems are under consideration, some of which may prove great potential obstacles at a later stage when the numbers of mixed farmers increase.

Stock.—Paradoxical as it may seem, Nigeria is understocked for the potential requirements. The estimated cattle population is about 3,000,000 and the natural increase about 300,000 per annum. It is estimated that the requirements of the country will exceed the figure for the natural increase, the demand coming from the ever-growing southern meat market, and from the distribution of cattle necessary for the maintenance of progressive mixed farming. Two main problems are being considered in connexion with the supply of cattle: firstly, how to maintain an adequate supply of working animals for the increasing number of mixed farmers, and secondly, how to supply good female stock for issue to these farmers. It is clear that mixed farmers must be encouraged to breed their own stock, and it will be undoubtedly profitable for them to do so. A long-range policy is under consideration, and the question of Native Administration stock farms is being studied. It is suggested that these should be incorporated into the Department's cattle policy and should be run in close co-operation with the existing Government stock farms, serving as extension farms, for the supply of cattle. One of the practical difficulties at the present time is the supply of cattle to mixed farmers. In certain areas, even now, cattle are not easily obtained in sufficient quantities. Distribution and supply are bad, with the result that cattle are obtained at uneconomic prices, and at a time when they are not required. The cattle are owned by the Fulani herdsmen, who do not wish to sell them except at tax time or unless they are forced to do so in order to raise money for debt, fines, &c. As the tax collection is at the end of the rains, the result is that the cattle are now purchased in their prime condition at the maximum price, and are kept throughout the dry season or until the prospective mixed farmers have harvested their crops and obtained money for their deposits.

Limitation of area of farms.—Consideration is also being given to the limitation of the area to be cultivated by mixed farmers. As previously mentioned, a scheme for the Zaria area is being formed to limit the size of holdings by a graduated tax, the basis being to allow for a progressive

family unit, but to tax capitalistic ventures. Mixed farming is designed to improve the peasant agriculture and to assist the peasant cultivators, and not to encourage a capitalist class.

Provision of capital.—There are two main problems: firstly, the establishment of new farmers when the scheme gains impetus and the numbers increase rapidly, and secondly, the provision of extra capital after establishment, for the purchase of carts, extra implements, and replacements of the original stock. At the present time the Native Administrations supply the money for the establishment of the mixed farmer, but as the system increases in size it is inconceivable that it will be possible for them to continue to supply the financial backing. The possibility of introducing co-operative principles is now under consideration as an alternative, and a detailed study of the whole problem of capital and co-operation is being made by the Registrar of Co-operative Societies and by an Administrative Officer.

Meanwhile, it has been decided to continue with the existing advance arrangements for a further period, and to carry out the above investigation. This decision was made for two reasons: (*a*) it is realized that the introduction of a system of co-operative societies would be of necessity a slow process and one which would require great care; (*b*) it is realized that at present the natives obtain their advances at the minimum charges and cost, which is a great concession in the introduction of a system. It is pointed out that no co-operative society could work on an interest basis of as low as 5 per cent. per annum, whilst at present the Native Administrations consider that the money invested in mixed farming brings in other benefits, such as increased wealth to an area, and do not require a direct financial return from their loans.

As the result of preliminary investigations [2] in an area in which mixed farming had been introduced, it was found that the situation did not necessitate the formation of co-operative credit societies, but that their existence would be a great advantage, not only for the needs of the mixed farmer but also for those of the hand-cultivator. It was recommended that four small experimental co-operative societies should be formed to supply credit for production purposes [2], especially for mixed farmers after establishment, for the co-operative sale of produce, and for village development. It was recommended also that these experimental societies should include hand-farmers as well as mixed farmers, but that the loans should not include the establishment of the latter [2], the object being that co-operation should be introduced and tried out in a small way on a village basis.

Another reason for the need of co-operative societies has been suggested. It has been indicated that, as a possible solution to the difficulties of dealing with large numbers of mixed farmers, co-operative societies should be formed, and that the Native Administrations, instead of lending money to individual farmers, should lend it to these societies, which would reduce the amount of accounting to be done by the Agricultural Officers and the Native Administration officials, as the accounts would be kept by the societies themselves under the aegis of the Co-operative Department. This could only be an ameliorative measure.

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Pt. III. A BRIEF COMPARISON OF CONDITIONS IN NORTHERN NIGERIA AND TANGANYIKA

The parts of Northern Nigeria which will be dealt with are the Provinces of Zaria, Katsina, Sokotu, and Kano in the North, and Ilorin in the Middle Belt. The former lie in the 10th and 13th degrees of northern latitude and the latter in the 8th and 9th. The parts of Tanganyika under comparison will be Sukuma and Zinza in the north-west, Nyamwezi in the central-west, and Uluguru in the east, which lie between 2 and 7 degrees, southern latitude. In all of these areas mixed farming is being introduced.

1. General

Population.—Although Northern Nigeria and Tanganyika are comparable in many ways, there are some striking basic differences. The first is the density and distribution of the population, which is largely controlled by such factors as the distribution of water, tsetse fly, and game. Northern Nigeria is densely populated with 11½ million people, but Tanganyika Territory has a total population of only 4½ million. Northern Nigeria is comparatively well watered; Tanganyika is not. The former, on account of the extreme temperatures and lighter vegetation, has a natural climatic control over the spread of tsetse fly, but Tanganyika with its more equable temperatures and dense bush conditions has no such limiting factor. In Northern Nigeria tsetse fly is very largely confined to riverine areas, whilst in Tanganyika vast stretches of country are infested by fly. Unlike Tanganyika, Northern Nigeria has virtually no big game. These factors very largely contribute to the main outstanding difference —the distribution of population, as quite apart from the large cities and big, walled villages, the people are more evenly distributed in Northern Nigeria than in Tanganyika, of which it is estimated that at least two-thirds is uninhabited tsetse-infested bush country.

2. Live Stock

A. The live-stock population of *Northern Nigeria* is estimated at about 3 million head of cattle, 1·5 million sheep, 4 million goats, 500,000 donkeys, and 200,000 horses. Cattle are the most important of the live stock. The majority are owned by the Fulani tribes, who are still nomadic in their habits, moving with their herds over large expanses of country and following the seasonal variations in the pasturage and water. The general drift of these tribes is in a southerly direction towards the large rivers during the rainless months of the year, followed by a return to the northern regions during the rains when pasturage and water are plentiful. Generally speaking, there is a wide distribution of the cattle population throughout Northern Nigeria.

In spite of the natives' reluctance to sell cattle, preferring rather to accumulate big herds, large numbers are slaughtered annually. In 1934, 125,200 crossed the Jebba Bridge en route for the southern meat markets, whilst 270,000 were slaughtered in the Northern Territories.

These figures indicate that the demands exceed the annual increase and that the cattle population is declining slowly.

Diseases.—The chief cattle diseases of Northern Nigeria are rinderpest, pleuro-pneumonia, black quarter, trypanosomiasis, and haemorrhagic septicaemia. In the past, cattle epidemics swept through the country in recurrent waves and decimated the herds. These have now been brought under control through the efforts of the Veterinary Department, and extensive immunization camps are scattered throughout the principal cattle areas to control disease. Curative treatment of trypanosomiasis is also being carried out on a large scale in those provinces where the disease is prevalent.

B. In *Tanganyika* the population and distribution of stock present a totally different picture, as conditions are very dissimilar. There is a greater numerical population of stock and a higher concentration in cattle areas. Cattle inhabit only one-third of the country, so that the conditions can be briefly described as 'islands' containing vast herds which are surrounded by a sea of bush. Tsetse fly and disease are the controlling factors. The live-stock population of Tanganyika is estimated at $4\frac{3}{4}$ million head of cattle, and 1·2 and 2·6 million sheep and goats respectively. Of the $4\frac{3}{4}$ million cattle, $1\frac{3}{4}$ million are found in the Northern Province belonging chiefly to the nomadic Masai; $1\frac{1}{2}$ million in the Central Province are owned by the semi-nomadic Gogo, and the agricultural Basukuma and Banyamwezi in the north-west account for the remaining $1\frac{1}{2}$ million.

Diseases.—In Tanganyika disease influences the distribution of stock to a far greater extent than it does in Nigeria. From a cattle map prepared by the Veterinary Department [3] the distribution of cattle shows that:

(1) Two-thirds of the Territory is tsetse-infested and cattle-free [3].
(2) About one-ninth is so arid that it is comparatively disease-free and stocked to saturation, the numbers being regulated by deaths from starvation [3].
(3) About two-ninths is free from tsetse owing to altitude and open nature of the country, and yet is understocked owing principally to enzootic East Coast fever causing a mortality of more than 50 per cent. among calves [3].

A study of the distribution of the live stock of the Territory shows clearly that the native husbandman is only capable of maintaining large flocks and herds on land the vegetation of which is indicative of arid or sub-arid conditions. Fertile soil blessed by a good rainfall cannot be utilized by him as it should be, that is, for the maintenance of a reasonable number of animals on land with persistent vegetation cover, since such conditions favour ticks, flies, and worms against the ravages of which the native is helpless without veterinary aid. Thus the parts of the Territory which are agriculturally the best are normally deprived of cattle and sheep by tsetse, ticks, and worms, and the only ways the native knows of making them available for stock are by measures that favour erosion and bring about soil aridity even in the presence of good rainfall. Conditions of natural aridity are found throughout much of Masailand, whereas a

state of artificial aridity unfavourable to disease and thus encouraging overstocking has been produced in Usukuma [3].

East Coast fever is the cause of more deaths of cattle in Tanganyika than all other causes put together [4]. It is one of the limiting factors in the distribution of cattle and one of the contributory causes of soil erosion. In Sukuma the area is kept free of the disease by an indigenous system of heavy stocking, as heavy grazing makes conditions inimical to the disease, and a few deaths from starvation are less costly than the risk of decimation. Other epidemic diseases such as rinderpest, pneumonia, black quarter, and foot-and-mouth disease also occur.

In Tanganyika the cattle population is reputed to be increasing; it is estimated that the natural increase is about 600,000 per annum, and that the total deaths, including those due to starvation, may amount to only 500,000, thus giving a net increase of 100,000 per annum.

3. Climate, Soil, and Vegetation

The climatic feature which is common to both sides of Africa is the division of the year into two well-defined seasons—the wet and the dry, though minor variations occur within the climate of the East Coast, where a short, dry period in the rains, which depends on locality and proximity to the coast, divides the wet season into two distinct periods.

The seasons vary, as they are controlled by entirely different conditions. On the West Coast the rains come with the south-west monsoon winds, and the rainy season occurs from April to September; while on the East Coast the big rains come with the monsoons from the Indian Ocean and occur from November to May, with short breaks in January and February. The chief characteristic of Northern Nigeria is the northern wind known as the 'harmattan', which begins at the end of September. This wind blows straight across the Sahara, is intensely dry, and laden with dust particles, which at times are so dense that visibility is reduced to a few hundred yards. As soon as the harmattan sets in everything becomes desiccated and all plant-growth practically ceases. Owing to its extreme dryness and the amount of evaporation it causes, it is at first a cool wind and the temperature falls rapidly, but later on, in February, March, and early April, it becomes hot and scorching, and it is during this period that high temperatures are recorded [5]. Temperatures of 100–115° F. by day, which fall to 55° F. or lower at night, together with extremely low relative humidities, such as 5 and 6, are frequently registered. Temperatures of such magnitude with variations so severe are unknown in Tanganyika.

Rainfall.—Variations in rainfall are too great to permit generalization, but it is sufficient to say that in Northern Nigeria they vary from 44 in. around Zaria, 35 in. near Kano and Katsina, to about 27 in. in the Northern Sokotu areas; whilst in Tanganyika they vary from 29–40 in. in Sukumaland, 28 in. in Unyamwezi, to 26–40 in. in the Eastern Province. Although no striking differences appear in the rainfall figures, the contrast in climate is reflected in the relative humidity, the Northern Nigerian figures being far lower than those of East Africa. This fact,

together with the extremes in temperature, is the cause of the exacting conditions found in the Northern Provinces of Nigeria.

Soil.—The areas under comparison are too large to allow anything but a generalization on soils. It is possible to find almost every kind of soil that exists, both in mechanical composition and in colour. Speaking broadly, the soils of Northern Nigeria are of a lighter texture and have a higher sand-content than those in the areas under comparison in Tanganyika. This is confirmed by the fact that in Northern Nigeria the cultivation of the arable land is possible with a ridging-plough (Ransome's D.Y. Plough) without any prior preparation, whilst in Sukuma it has been found that the soils cannot as a rule be ridged with such ploughs unless previous cultivation has been carried out.

Vegetation.—The vegetation of Northern Nigeria and parts of Tanganyika bear a striking similarity. Plant and tree associations common to both areas occur frequently, with the exception of the pure stands of 'Dorowa' trees (*Parkia filicoidea*), which are to be found in Zaria Province and give rise to the characteristic park-like landscape. In the other areas the vegetation consists of typical 'tree savannah' country including associations of 'doka' (*Isoberlinia doka*), species of Acacia, baobabs (*Adansonia digitata*) and silk cotton trees (*Eriodendra orientalis*); whilst in the far north the vegetation consists chiefly of thorn 'scrub savannah' composed of Acacia *verek*, A. *Seyal*, A. *Fistula*, A. *Senegal*, A. *Albida*, A. *Arabica*, and open country with scattered baobab trees and Dom palms.

In many places the country reminds one of Tanganyika: for example, the Isoberlinia bush can be compared with the Kahama area; and the open type of country in the Sokotu Province is similar to many parts of Sukuma. From a brief ecological survey in the Zaria Province and from general observations made during his visit to Nigeria, Mr. B. D. Burtt found that 59 per cent. of the trees is common to both east and west.

Certain similar tree associations, known to hold tsetse fly in East Africa, hold no fly in Northern Nigeria, their absence being due to the severity of the climate and the extremes of temperature. Similarly, under comparable bush conditions, there is a striking absence of big game in Northern Nigeria.

4. Social and Agricultural Conditions

In Northern Nigeria the cultivators of the soil are mostly the Hausa, with the pagans in southern Zaria and the Yoruba in the Ilorin Province. Their counterparts in Tanganyika are the Basukuma in the north-west, the Banyamwezi in the west-central area, and the Waluguru in the Eastern Province. Great differences occur in the social and agricultural conditions. In Northern Nigeria, speaking generally, the cultivators of the soil do not own any cattle, as cattle of Zebu type are herded by the nomadic Fulani. In Tanganyika, however, the majority of the Basukuma are both cultivators of the land and owners of cattle. In the other areas under discussion, such as the Eastern Province, the natives live in tsetse-fly areas and consequently have no cattle.

The Hausa are an industrious and highly money-conscious people with considerable skill in cotton spinning, weaving, dyeing, leather and metal work. They have a highly-developed social system and a literature of their own. Socially they are further evolved than the tribes in Tanganyika, though in many ways agriculturally they are very similar. One of the main differences would appear to be a greater need for the acquisition of money. The Hausa desires to obtain wealth so as to improve his social status. He requires money also for the two Moslem festivals (which involve the purchase of new gowns), for the purposes of dowry, for the entertainment of his friends and relatives, as well as for his tax [2]. 'The Hausa and his wife are ashamed to appear at a festival or ceremony in the clothes they wore "last time". Every one would say, "so and so is down and out, nothing he had on was new"' [2]. 'The first thing a Hausa does, if he gets on a little, is to buy a horse (cf. a Fulani, who would buy cattle). It is possible to re-sell a horse at a profit after getting flesh on to it with grass and grain, but buying a horse is usually mere swagger' [2]. Another striking difference is the Hausa's love for trading; he is a born middleman and jack of all trades. When describing the Zaria farmer, Mr. Giles wrote . . . 'the Zaria farmer does not care much for trading expeditions. But he is ready to buy, sell or lend anything, from cloth and unripe crops to kolas and old iron, as soon as he has the money to do it' [2].

In Tanganyika, on the other hand, the natives have quite a different economic outlook. They are less money-conscious, having been in contact with a cash economy for a very much shorter time, and do not go in for middleman trading like the Hausa. In many parts they desire to obtain wealth only for the purchase of cattle; this refers especially to the Basukuma.

As farmers, the Hausa bear close resemblance to the Basukuma, being no better as agriculturists, if as industrious; both are mainly cereal eaters, and shortage of food is not unknown from time to time. In both countries, where land is available, the native shows real discrimination when choosing fields for his crops, and knows exactly which crops are suited to any particular type of soil. After land has been selected for the food crops it is usual to find that ground-nuts are grown on light, sandy soils and cotton on the heavy land.

In Nigeria, except for the densely populated areas around Kano and other big cities, the people live in old walled towns and villages from 3 to 10 miles apart, and in hamlets where farmers (from one family to 50 or more) have moved out to settle in the bush. Most of them follow methods of shifting cultivation and wherever possible have their land 'kraaled' by the Fulani. In Tanganyika, on the other hand, the mode of living is governed by local circumstances. In the open country of Sukuma, people live in family groups or 'makaya', scattered over the country, each 'kaya' with its farm near to it; whilst in tsetse-fly country and in bush areas, such as the Eastern Province, containing game, people live together in villages or hamlets and cultivate their farms in close proximity to each other. With the exception of a few isolated tribes, the natives of Tanganyika do not use manure. In many areas, however, they know its value, but for various reasons, of which the most important is transport,

they find its use uneconomic except in areas of considerable population-pressure where virgin soil is unobtainable. The notable exceptions are the Kara, Chagga, Sandawe, and Eraku peoples.

Crops.—The crops grown are similar, though exceptions are observed. Great variations occur in the various proportions of the crops grown, depending on climatic conditions. In Nigeria it was interesting to note the correlation between the crops and the rainfall. In the 'Middle Belt' (Ilorin) maize and yams were the predominant crops, and there was a gradual transition from these crops to yams (under shade) and sorghums or millets in the Zaria Province—to no yams or sorghums, but early millets and cowpeas in the far north of the Sokotu Province.

The main food crops in Northern Nigeria are guinea corn (sorghums), 'gero' or bulrush millet (*Pennisetum typhoideum*), 'maiwa' (*Pennisetum spicatum*), rice, cassava, sweet potatoes, cowpeas, beans, coco yams (under shade), and crops of the house plot such as okra, chillies, onions, and tobacco. Maize is grown only in the Middle Belt.

The main grain crops of both countries are sorghums and millets. In Tanganyika greater quantities of maize are grown, especially in the coastal areas. Other differences are that in Tanganyika yams are not grown to any extent, whilst pigeon peas and legumes are grown in greater quantities.

The main cash crops of both Northern Nigeria and Tanganyika Territory are cotton and groundnuts, and it is customary to sell excess quantities of foodstuffs in good seasons.

Native Administrations.—The administration of the people in both Northern Nigeria and in Tanganyika is based on the principle of Indirect Rule, and there is a great similarity in the operation of the Native Administrations and in their relations with the people. There are, however, great differences between the two countries, due mainly to the age, size, and wealth of the organizations, and to the differences in population. In Northern Nigeria the Native Administrations are far more advanced than they are in Tanganyika, having been established much longer. They are also far larger and their treasuries are much richer. In addition to the greater number of taxes, they receive a larger percentage of the tax. To illustrate the size of a Northern Nigerian Native Administration the figures are quoted for Kano Emirate, where there is a population of 2 million of which 80,000 live in the city [6]. The revenue 1932–3 amounted to £233,000 and in 1933–4 to £200,000; the fall was due to the increase in Government's share of the tax, which was raised from 30 per cent. to 40 per cent. [6].

In Northern Nigeria the organization of the Native Administration lends itself to the extension of improved agricultural methods, for every one in the state, from the Emir down, is a farmer. Not only do the Native Administrations provide the machinery for the agricultural-extension work but they also provide the fuel—the financial support to run it. The Native Administrations were quick to realize that the tax was most easily paid in areas where the Agricultural Department was working and when, in 1933, a curtailment of the activities of the Agricultural Department was threatened for financial reasons, they agreed

to share with Government the cost of agricultural-extension work in order that it should continue [7].

In Tanganyika such a state of affairs does not exist. The Native Administrations are much smaller and their budgets do not allow for the employment of permanent European officers or for the advance of loans to natives. In parts of Tanganyika the Native Administrations are still in the stages of infancy, and the diminutive size of some units is due to the stage of social organization which, unlike Northern Nigeria, had not been accelerated by extensive conquest from outside.

Stages of Development

From the description of the work in Northern Nigeria, and from the comparison of conditions, it will be seen that the problems of introducing mixed farming in the two countries are set in widely dissimilar surroundings and are at different stages of growth.

Nigeria

In Nigeria the extension of mixed farming is undertaken entirely through the Native Administrations. The success of the system, which can be judged by the fact that mixed farming is now beginning to take a place in native agriculture, was undoubtedly due to the care exercised in developing this system of farming, and to the trouble which was taken to convince the Native Administrations of its value, before any attempt was made to apply it to Native Agriculture. It was not until their confidence had been won that they were approached with a view to supporting the scheme.

The successful growth of the Nigerian system is due undoubtedly to three factors: firstly, it has the backing of powerful Native Administrations; secondly, simplicity has been the keynote of all the work; and thirdly, in the development of mixed farming there have been no dealings in land, such as the laying out of holdings, land-settlement schemes and the like, which may be required on a small scale when establishing mixed farming in such areas as the tsetse-infected, thick bush country of the Eastern Province of Tanganyika.

Approach.—It will have been seen that the Native Administrations provide all the financial assistance for the extension work; this includes not only considerable sums of money for the purpose of advances to natives, but also for the training and maintenance of staff.

Simplicity.—An important factor contributing to its success is that the system has been kept on the simplest basis. Mixed farming has been directly grafted on to the existing native agriculture with as little disturbance as possible. A farmer merely obtains cattle, builds a pen, and starts on his present farm to adopt the methods of improved agriculture. The first step is to get him to make and use manure, and to look after his cattle, and until this is done there is no attempt to get him to make any other improvements. This step is considered sufficient, even in a country where the application of manure by 'kraaling' has been taking place from time immemorial. Visiting many areas in which mixed

farming had been established, one was impressed immediately by the flexibility of the system and the ease and simplicity of its introduction. It is designed to suit both large and small farmers. For example, around Maigana in the Zaria Province, it was interesting to note that there were two distinct types of mixed farmers. Firstly, the 'intensive' mixed farmer who works on a 10–12-acre basis with his pair of bullocks and who manures his land with pen-manure, and secondly, the 'extensive' mixed farmer who has too many cattle to house in a pen and who manures his land by intensive 'kraaling'. This second type of farmer is generally a settled Fulani or progressive Hausa, who cultivates 20 acres or more.

Methods.—A desirable feature of this system is that, although introducing mixed-farming methods, it does not deal with the allocation of land, so that, instead of tending to individualize the farmer on a demarcated holding, it tends to foster *esprit de corps* among mixed farmers.

One could not fail to be impressed by this spirit, particularly in the Maigana area. Mr. Giles in his survey of the Hausa peasant wrote: 'One cannot fail to be impressed by the spirit of co-operation among mixed farmers. We have the same secrets, and we are like full brothers. Everywhere where there are a few Hausa mixed farmers they co-operate over work and over pasturing; they bring their cultivators or ploughs to one farm, finish that, and move to another; their boys take it in turns to take all the cattle to pasture. No one ploughs with a wooden plough if there is an iron one in the village. If a new farmer is still unhandy with his plough, or his cattle are not fully broken, a neighbour brings one or both of his cattle to help him; in return the other farmer sends his sons to help his neighbour at hand-weeding' [2].

Thus simplicity and the extension of collective assistance aid the introduction of mixed farming, and avoid the dangers of individualization, which have been so clearly seen in India.

Tanganyika

Whereas Nigeria, after sixteen years of experience has already begun the extension of mixed farming to native agriculture, this Territory is only just reaching the end of the experimental stage. In Tanganyika conditions are more diverse and circumstances more complicated. Quite apart from the introduction of animal husbandry into native agriculture, it will have been seen that concomitant problems such as tsetse-fly, East Coast fever, and in the semi-arid regions the resultant evils of overstocking and erosion, all have to be faced.

Hitherto, in view of the extreme complexity of the problems, complete supervision was essential, and the introduction of mixed farming had to take place in conjunction with peasant-holding schemes. The decision to combine a study of these two problems under the Agricultural Department, quite apart from the difficult conditions, was largely influenced by the knowledge that the Native Administrations could not afford to finance large ventures, and to the fact that the Government had been given the most generous financial support by the Empire Cotton Growing Corporation.

It is now considered, however, that with the experience and data which have been obtained from these centres, the time has arrived for the extension of mixed farming into native agriculture. It will have been seen that in Northern Nigeria the primary aim of mixed farming is to get the peasant farmers to make and use pen-manure, but in Tanganyika, due to the complex conditions, the first aim was to establish some peasant holdings and to obtain experience as quickly as possible.

Whereas in Nigeria mixed farming started with the evolution of the Zaria system having a demonstration unit as an example, the extension of the system has been confined very largely to the endeavour to get farmers to make and use manure. Similarly in Tanganyika, after obtaining experience of the objectives, a policy of extension must be devised in order to apply these improved methods to indigenous rural economy.

It will have been seen that the conditions in the two countries are so dissimilar that the adoption of the details of Nigerian practice is precluded and extension policy in Tanganyika must be evolved from experience there. It is clear, however, that the maintenance of soil fertility must be our objective, and that the extension of mixed farming is necessary to achieve this end. In this connexion it is possible, however, to benefit from Nigerian experience by the adoption of the three basic principles on which the success of their system is founded, namely:

1. All extension work is carried out through the Native Administrations.
2. Simplicity is the keynote of all the work and one improvement at a time is grafted on to indigenous agricultural practice.
3. In the evolution of mixed farming there has been no land allocation by European Officers, and such extra land as has been required by the peasant farmers has been obtained in the usual manner from the village headmen.

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FIG. 11. Donkeys bringing in loads of groundnuts at Kaura Namoda market. Pack oxen and camels are also seen at this place

FIG. 12. Zaria native produce market

THE TICKS OF EAST AFRICA

Pt. II. TICK-BORNE DISEASES AND THEIR CONTROL

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Tick-borne Diseases

The study of ticks has attracted wide attention mainly on account of the serious diseases they transmit. In East Africa the subject is regarded as one of great economic importance and is considered along with problems of rinderpest, pleuro-pneumonia, and human and animal trypanosomiasis. Every species of domestic animal is subject to tick-infestation, which is often extremely heavy; and to one or more tick-borne diseases. Man, himself, is liable to contract diseases or fevers transmitted by, or associated with, ticks.

The specific diseases known to be transmissible by ticks in East Africa are shown in the following table:

Diseases, Parasites and their Vectors

Disease (and host)	*Causal organism*	*Vectors*	*Disease (and host)*	*Causal organism*	*Vectors*
East Coast fever (bovine)	*Theileria parva*	*R. appendiculatus* *R. capensis* *R. evertsi* *R. simus* *Hy. anatolicum* *Hy. dromedarii* *Hy. planum*		*Theileria mutans*	*R. appendiculatus* *R. evertsi* *R. simus*
			Nairobi Sheep disease (ovine, caprine)	*virus*	*R. appendiculatus* *A. variegatum*
Heartwater (bovine, ovine, caprine)	*Rickettsia ruminantium*	*A. variegatum*	Biliary fever (equine)	*Nuttallia equi*	*R. evertsi*
Redwater (bovine)	*Babesia bigeminum*	*B. annulatus decoloratus* *R. appendiculatus* *R. evertsi*	Malignant jaundice (canine)	*Babesia canis*	*H. leachi* *R. sanguineus*
Anaplasmosis (bovine)	*Anaplasma marginale*	*B. annulatus decoloratus* *R. simus* *R. sanguineus* *R. bursa*	Spirillosis (equine, bovine, ovine)	*Spirochaeta theileri*	*B. annulatus decoloratus* *R. evertsi*
Tick-typhus or Tick-fever (human)	*Rickettsia*	*R. sanguineus*	Relapsing fever (human)	*Spirochaeta* (*Borrelia*) *duttoni*	*O. moubata* *O. savignyi*
Fowl piroplasmosis (avian)	*Aegyptianella pullorum*	*Argas persicus*	Spirochaetosis (avian)	*Spirochaeta anserina* (*marchouxi*)	*A. persicus* *O. moubata*

It is not proposed to discuss the nature of the diseases conveyed by ticks, but the mode of transmission of the micro-organisms and their fate in the intermediate hosts are subjects of considerable practical import. *Babesia bigeminum*, the causal organism of redwater in this country, can be transmitted by *B. annulatus decoloratus*, *R. appendiculatus*, and *R. evertsi*. It has been proved [1] that the first tick is the usual vector and that the last two are rather exceptional carriers of the disease. In *Boophilus* the protozoon is conveyed from one generation to another

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through the eggs of an infected female tick. It may persist in ticks which have fed on horses; and when the progeny of these ticks feed on cattle they can infect the animals with redwater. The *Babesia*, therefore, passes from one generation of ticks to another which does not always lose infection when fed on an insusceptible animal. Daubney and Hudson [2] have shown that the virus of Nairobi sheep disease passes through the eggs of *R. appendiculatus* and that larvae of an infected, engorged female can transmit the disease. They proved that after infecting a sheep the transmitting stage of the tick loses its infection if it drops before the commencement of the temperature reaction which that tick evoked. If, however, the incubation period of the disease should be so short that the reaction commences before the transmitting stage has finished its feed, some infective blood is taken into the gut and the tick is again infective through the next instar.

Lounsbury [3] showed that *Rickettsia ruminantium* of heartwater is transmitted to susceptible animals by nymphae of *A. hebraeum* that fed as larvae on a reacting beast; that adults from infected nymphae are pathogenic, and that adults fed on a cow as nymphae but on a sick animal as larvae can also transmit heartwater. He showed also that infection can be conveyed to a long-recovered animal by infective nymphae. In Kenya—and presumably throughout East Africa—*A. variegatum* replaces *A. hebraeum* as an agent in the transmission of heartwater. Daubney [4] was able to show that unfed adults of *A. variegatum* from infected calves conveyed the disease to sheep. *Rickettsia ruminantium* does not, apparently, pass through the eggs of the *Amblyomma* ticks. *H. leachi* and *R. sanguineus* are the vectors of tick-fever (Malignant Jaundice) of dogs. In the former, *Babesia canis* passes through the eggs of an infected female, remains dormant (or develops) through the larval and nymphal instars and appears in the adults by which it is transmitted to the host. In the case of *R. sanguineus* also, the parasite is transmitted through the egg; but there appears to be a stage-to-stage infection of the tick. Brumpt [5] found that infected *R. sanguineus* do not necessarily clean themselves of infection after feeding. He showed that *Babesia canis* can be transmitted to dogs by a strain of the tick reared for five generations on hedgehogs. *Nuttallia equi* of biliary fever of horses is taken up from infected animals by the larvae and nymphae of *R. evertsi* and transmitted to horses by the adult ticks. It appears that the egg of the tick is not involved in the life-cycle of the parasite and, therefore, neither the larvae nor the unfed nymphae of the two-host tick carry the disease. *Theileria parva*, the parasite which causes East Coast fever, does not pass through the egg of *R. appendiculatus* nor, it may be assumed, of the other tick-vectors. A larva hatching from eggs laid by an infected female cannot, therefore, transmit the disease. A larva or nympha which has fed on a reacting animal will, however, pass on the disease to susceptible animals as a nympha and adult, respectively. An infected tick will clean itself of *T. parva* when fed on a susceptible or non-susceptible animal whether it be a bovine or not.

There are other tick-borne diseases which cannot be dealt with in a short space. Attention may be drawn to the non- or less specific diseases

associated with, or caused by, ticks and the lesions from tick-bites. Daubney [6] has associated bovine lymphangitis with the open sores and lesions made by *Amblyomma* species. Many cases of anaemia and ulcerative cellulitis following heavy tick-infestations have been observed in experimental animals and in the field. Prolonged irritation and the sucking of blood by innumerable ticks must affect milk-production and the constitution of high-grade and pure-bred cattle common in the Kenya highlands. The slow development, unthrifty condition, and not infrequent emaciation are often due to the abundance of ticks feeding on cattle and horses especially. Heavy infestation in East Africa indicates the presence of ticks in hundreds of thousands; it involves several species whose life-histories and habits—on and off the host—are often different. Such infestations have been observed on cattle, horses, dogs, rodents, and many game animals.

It is obvious that a great deal is already known of the nature of tick-borne diseases and the manner in which they are transmitted. There are, however, many gaps to be filled in order to complete the information on the parasites and the role played by the vecting ticks. For example, can the character and virulence of the parasite be changed by modifications in the life of the tick or by a change in the vecting species? What is the earliest stage in a reaction of an animal that a tick can take up infection, and what is the latest stage? Do all vectors provide similar facilities for the development and transmission of the parasites in each of the diseases? Is the parasite able to recover its virulence in a tick after a series of sub-inoculations of infected blood into animal hosts? What happens to the parasites or micro-organisms when infective ticks are kept unfed for considerable periods? To some of these questions only partial answers can be given. Observations on *R. appendiculatus* at Kabete prove that unfed larvae will survive for at least 284 days, nymphae for 609, and adults for 1,013 days. It has also been noted (Fotheringham and Lewis, unpublished report) that *T. parva* in unfed nymphae and adults disappears when the ticks are kept for about 300 days, although in one case the parasite seems to have lived for over 910 days. Do some other parasites perish in the ticks before the latter die, or do they live as long as the tick? The longevity of *R. sanguineus* under laboratory conditions is 527 days; that of *A. gemma* and *A. variegatum*, 493 and 732 days, respectively, and that of *R. pulchellus* 417 days and over.

The foregoing suffices to show the complications of the tick problems in East Africa and how intimately connected is the reduction or eradication of ticks with any scheme for the control or extermination of tick-borne diseases.

Measures for Control

The principles on which different methods of control are based have been explained and discussed by many experienced workers in numerous countries.

In East Africa, control of ticks involves all classes of domestic animals and, in some districts, a consideration of game, birds, and vermin.

The primitive custom of evacuating localities where East Coast fever

and other infections were rife was freely practised by the nomadic tribes, especially the Masai natives of East Africa. Moving from place to place until mortality among the stock ceased, they ultimately escaped but left infection along their trail either for other herds to pick up, or so that the contaminated route might be left untouched for long periods and infection die out. With decisions to confine the nomadic peoples within stipulated boundaries, the extensive evacuations and movements came to an end.

The utilization of 'temperature camps' for the control of East Coast fever in South Africa and in East Africa was a method based on the incubation and reaction periods of the disease and on a knowledge of the moulting periods of *R. appendiculatus*. It was instituted as a temporary measure to control the disease (or an outbreak) when a dipping-tank was not available. A camp comprised enclosed clean paddocks. The cattle were moved from one to another on the evidence of reaction by means of daily temperatures and symptoms of the disease. A herd of cattle was put into a first paddock for a period covering the longest known time for incubation of the disease. Animals that showed no reaction for that time were moved to a second clean paddock, whilst those that reacted remained in the first or were slaughtered. If one or more animals in the second paddock showed symptoms of East Coast fever, or if the temperature indicated the development of the disease, they were returned to the first paddock. The cattle were kept in the second paddock for 16 or 18 days—the normal known time a nympha took to moult. If there were no signs of disease at the end of this period, the cattle were considered safe from further infection in that outbreak and released.

More general methods of control that are recommended include slight modifications of the old measure for the starvation of the tick-population by complete de-stocking of infested areas, the rotational system of grazing pastures, and a combination of these two, using the stock as collectors of ticks to be destroyed by an acaricide. Also, animals not susceptible to the tick-borne diseases may be utilized to collect the ticks for destruction. In extensive tropical areas, burning of grass at specified periods is considered effective in reducing heavy infestations of pasture-lands. Dipping is universally recommended. Spraying is suggested possibly as an alternative to dipping. Hand-dressing is advised when immersion does not affect those ticks situated in parts of the body inaccessible to the dipping fluid, or when frequent dipping is not possible or is uneconomic.

Space precluding a detailed discussion of the subject, it must suffice to say that, despite the numerous methods of control that have been advocated, there are yet several aspects of the problem that seem to need consideration and more detailed investigation if recommendations to the farmers are to prove more acceptable and effective. In East Africa it is proposed that the subject be dealt with by the East African Central Veterinary Research Institute at Kabete. It is to be borne in mind that dipping of cattle and sheep in particular is necessary all through the year and not, so far as is known, for a few months only.

The function of control is to safeguard animals from disease and death, caused in this instance, directly or indirectly, by ticks. Investigations into the treatment of the diseases already contracted and the prevention of mortality by immunization are obviously necessary. The method of control must also conform, as closely as possible, with the appropriate systems of animal and other industries in the districts. The dipping fluid should be easy to prepare and adequately lethal.

It has to be acknowledged that the development of animal industry in East Africa has not reached the stage it has done in the older countries. The farming of high-grade and pure-bred stock, however, has progressed beyond a hazardous venture. The farms are large, markets are at a distance, fencing of extensive acreages is costly, and the quality of the grazing is high only in a few localities. Concentration of stock in enclosed paddocks is not always practicable. The stock owned by natives wander far and wide and are often driven many miles for grazing and water.

Nevertheless, dipping is widely practised in the more advanced European stock farms. It is being accepted as a measure for tick-control on crop farms and in mixed-farming areas; and even some of the progressive natives are eager to adopt it in their reserves. Many farmers realize the necessity for dipping at frequent intervals throughout the year. They may have fenced only their boundaries or divided their farms into fenced paddocks. Others also dip their stock, but have been unable to fence. Where farms are well fenced and dipping has been practised with regularity, it has been shown that ticks can be eradicated even in the midst of heavily infested country. Regular dipping is not always practised and the intervals between dippings vary a great deal. A farmer may not wish to eradicate *Boophilus* ticks because his cattle would thereby not acquire a natural immunity to redwater and anaplasmosis. Another believes, or has experienced, that dipping during the rains is harmful to his stock or reduces the milk-yield; or the cattle during the dry period are in so poor a condition that they cannot withstand the effects of immersion. This periodic, rather than continuous, dipping at short intervals and frequent relaxation of the practice tend to invalidate the real purpose of the operation and to prolong indefinitely the necessity for dipping. Dipping strikes at the root of the evil, kills the potential source of all tick-borne diseases, and prevents further reproduction of ticks.

The intervals between immersions of the host are based on the shortest time it takes the different species and stages of ticks to feed on the animal. *Boophilus* remains on a host for about 28 to 34 days, larvae of *R. appendiculatus* from 3 to 12 days, nymphae for 6 to 15 days, and adults from 6 to 8 days. The larvae of *A. variegatum* remain attached for 5 to 8 days, nymphae for 6 to 13 days, and adults 14 to 22 days. The larval and nymphal stages of *R. evertsi* feed for 12 to 20 days and adults for 6 to 10 days. To be effective against *Boophilus*, dipping should be practised at intervals of about 2 to 3 weeks, but against *R. appendiculatus* the interval should be reduced to 3 days. In practice, however, the 3-day interval is employed to reduce mortality among

cattle when an outbreak of the disease occurs, and after a few months a 5-day interval in a 7-day strength of dip is usually resorted to. The larvae of *Amblyomma* are not often found in large numbers on domestic stock: the nymphae are more common but not as numerous as the adults. A 5- or 7-day interval would assist in bringing the immature *Amblyomma* to a dip; and it is also effective against adults. Other circumstances influence the farmer in his choice of intervals, which may differ from 3-, 5-, 7-, 10-, 14-, to 21-day intervals.

The dipping solutions most commonly used in Kenya are the Laboratory dip, arsenite of soda, and proprietary brands containing arsenic compounds, the standard requirements of the latter being 0·08 per cent. As_2O_3 in a 3-day dip, 0·16 per cent. As_2O_3 in a 5- or 7-day dip, and 0·24 per cent. As_2O_3 in a 10- or 14-day dip.

It has been asserted that some dipping fluids confer a protection from tick-infestation for certain periods which may extend to 14 days or more. Such a property in a dipping mixture or compound would obviously modify the intervals necessary between immersions. It would have a far-reaching influence on tick-eradication policies, especially if the keeping qualities of the dip were not impaired; and farmers would be more ready and willing to adopt the measure. An effective protection for such periods would result in the reduction of labour, would be easier on the stock, nullify fears of infection by diseases and, at the same time, simplify the starvation and eradication of the potential sources of tick-borne diseases—the ticks.

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THE LOESS SOILS OF THE BEERSHEBA REGION OF PALESTINE

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THE southern end of Palestine has the shape of a triangle with the apex at Aqaba and the base represented by a line drawn from Gaza to Beersheba. This district, the biblical Negeb, has of late been frequently discussed as a territory offering possibilities for Jewish colonization. The area of the Negeb is about 12,500 sq. km., 9,380 of which are classified as 'southern desert', and 3,200 as 'Beersheba area', of which 1,640 sq. km. are regarded as cultivable land [1]. No soil survey has ever been carried out in this region, but it is known that wide stretches possess only an extremely shallow layer of soil, quite unsuitable for any kind of cultivation. In fact, most of the land is stony desert, the soil being covered with heaps of gravel and stone fragments. Dune sands and loams are found in the western part, and the Beersheba district in particular is covered by soils of aeolian origin. Only these loess soils are dealt with in this paper.

Climate.—Rainfall is sporadic, and in many years no harvest at all is possible. Table 1 gives the rainfall at various places in this region [2].

TABLE. 1. *Mean Annual Rainfall in the Negeb (mm.)*

Year	*Auja Hafir*	*Khan-Junis*	*Ras Zuweira*	*Kurnub*	*Asluj*	*Beersheba*
1933–4	..	261	104	70	..	336
1934–5	28	310	149	75	55	243
1935–6	37	130	99	43	48	130
1936–7	69	339	122	65	86	268
1937–8	284	302	101	130	170	236

No detailed data with regard to temperature are available, but it may safely be assumed that the mean annual temperature exceeds 20° C. Winds are sometimes very strong, and the whole area is afflicted by dust storms.

Geology.—The geology of the Gaza–Beersheba district was recently described by Picard and Salomonica [3]. The oldest formations are cretaceous and are found in the neighbourhood of Beersheba. Besides hard Turonian limestone, series of chalk, breccious flint, and phosphatic limestone belonging to the Campanian-Maastrichtian are also found. Then follows the Danian zone and soft Eocene limestone. Oligocene is represented by a quartzitic chalky marl and hard limestone. Sporadically, marl of Miocene Age is also exposed. The main rocks of Pliocene Age are sandstones and marls. The gravel on the mountain slope and all the older dunes of the coastal plain belong to the Pleistocene, the latter being often covered by a dark-brown loamy soil which should be distinguished

from the loess. According to the above authors [3], the loess is partly of aeolian and partly of fluviatile origin. Alluvial loam covers the slope of the mountain border, especially in the northern part. This short survey shows that limestone and sandstone are the soil-forming rocks.

Hydrology.—The enormous amount of rain that falls in the southern part of the Judaean highlands drains mainly into the Negeb. The gorges (wadis), dry in summer, become filled with muddy, roaring torrents in winter, sometimes causing great devastation. The Wadi Shari'a and the Wadi Ghazza should be especially mentioned, the latter forming a bed ¼ km. in breadth south of Gaza. Since much of the rain caught in the mountains probably flows underground to the Negeb, the hope of striking large subterranean reserves of water by boring was considered justified. Borings made by the Government of Palestine showed that such strata exist generally at great depth and are very saline. Only the dune region yielded water of better quality, but of limited amount. Many shallow wells show water of better quality, but the amount of water obtainable from them is everywhere insufficient for agricultural purposes.

Two complete analyses of water were made by the author, the first being a sample of the abundant supply of a deep water-horizon (at km. 26 on the Beersheba–Gaza road), and the second a sample from a shallower horizon (near Beersheba) which, however, yielded insufficient water for agriculture.

TABLE 2. *Analyses of Water* (*mg. per litre*)

	Na	*K*	*Ca*	*Mg*	*Fe*	HCO_3	*Cl*	SO_4
1. Boring at km. 26, Gaza–Beersheba road .	1,927	36	353	250	tr.	164	3,553	944
2. Boring near Beersheba.	276	6	130	147	tr.	232	507	323

Analysis shows that the water from well No. 1 contains 7,637 mg. of salts per litre, and is therefore absolutely unfit for agricultural purposes. Since, however, in some instances water containing only 1,500 mg. Cl per litre was found, the author, in co-operation with the Government Departments of Development and Agriculture, started some experiments on the resistance of various plants to salts, the results of which will be given below.

Soils.—The loess territory owes its origin mainly to the dust-storms of the desert. This fact was first recognized by Range [4]. Near Wadi Ghazza, for example, this author found Egyptian potsherds of the second millenium B.C. beneath a layer of loess 3 m. thick. Even to-day the aeolian movement of these soils can readily be observed. On the other hand, as mentioned above [3], loess-formation in the Negeb may in some cases be attributed to fluviatile re-deposition. The thickness of the loess seems to vary greatly between 3 and 15 m. The loess is yellow, and microscopic examination shows it to consist mainly of grains of fine quartz intermixed with chalky particles, which often clearly indicate

a fossil origin. Chemical analyses of two typical loess soils, which were absolutely uniform in structure, gave the following results:

TABLE 3. *Analyses of Loess Soils*

Sample No. 1 taken near Beersheba and Sample No. 2 taken at km. 26 on the Gaza–Beersheba Road (per cent.)*

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	CO_2	H_2O	N
No. 1	59·97	4·30	3·40	12·70	1·58	0·61	0·97	0·11	0·28	10·93	6·24	0·06
No. 2	66·70	0·64	4·33	14·15	1·61	0·21	0·11	0·20	0·05	8·25	2·59	0·07

The pH of these soils was 7·8 and 7·9, respectively.

* On soil No. 2, hard chalky sandstone is struck at a depth of only $7\frac{1}{2}$ metres.

These analyses show that the loess soils are rich in calcium, but poor in iron and alumina. Nevertheless, mechanical analysis shows that the loess contains a high percentage of fine particles, mainly belonging to the 'fine sand' fraction. Even ordinary chemical analysis indicates comparative richness in mineral nutrients and deficiency in nitrogen. The mechanical composition of the loess is given by the following typical analysis:

TABLE 4. *Mechanical Analysis of a Typical Loess Soil (per cent.)*

Coarse sand	*Fine sand*	*Silt*	*Clay*
0·40	61·11	24·62	13·87

These loess soils are easily permeable to water and air and of a texture most suitable for cultivation. The drainage also is excellent, as can be seen from the easy absorption of rain-water. The lime-content of these soils averages about 25 per cent. and is most advantageous. The reserve of mineral nutrients was determined on two samples by Neubauer's method and gave the following results:

TABLE 5. *Neubauer Analysis of Loess Soils*

	P_2O_5 (*mg.*)	K_2O (*mg.*)
Sample 1 (Beersheba)	9·3	21·5
Sample 2 (5 km. north of Beersheba)	7·8	29·0

These figures show the soils to be sufficiently provided with nutrients for the growth of barley, the main crop of the Negeb. The comparatively high amount of nutrients is easily explained by the fact that, owing to climatic conditions, there is no leaching of salts; during the greater part of the year there is capillary movement from the deeper layers to the surface, where the water carrying the salts evaporates. On the other hand, loess soils are deficient in organic matter and nitrogen, a fact for which climate is responsible. Various analyses showed the nitrogen-content to vary between 0·05 and 0·07 per cent. Given sufficient water and nitrogenous fertilizers, these soils are capable of producing excellent yields.

Irrigation experiments with loess soils.—Rainfall being very sporadic,

experiments were carried out to determine the salt-resistance of various plants grown on these soils and irrigated with saline water (the only water available) containing varying amounts of salts [1].

In the greenhouse experiments, soil No. 2 was used and the water was brought from the well at km. 26, Gaza–Beersheba road, the water being diluted with distilled water to various concentrations.

In the field experiments near Beersheba, water of the Beersheba town-supply was used for the lowest concentration (160 mg. Cl per litre) and for the higher concentrations the well-water No. 2 at the experimental field (containing *c.* 500 mg. Cl per litre) was employed. In order to obtain higher concentrations sodium chloride was added in varying amounts, a justifiable procedure because in Palestine salinity is always due to the presence of this salt [5]. The plants were sown in empty asphalt drums, penetrating the soil to a depth of about 70 cm. (The bottom of the drums was, of course, removed.) The small experiment station was unhappily destroyed during the disturbances.

The subjoined table records the salt-resistance of various plants in some of our experiments. The harvest obtained when irrigating with water containing only 100–350 mg. Cl per litre is put at 100, and the other figures show the percentage of harvested material when the plants were irrigated with water of higher salinity. All experiments were run in duplicate and sufficient nutrients were added.

TABLE 6. *Percentages of Yield obtained after Irrigation with Water of Varying Salinity*

Mg. Cl per litre:	*100–350*	*500*	*750*	*1,000*	*1,500*	*1,750*	*2,000*	*2,500*	*3,500*
Potatoes* .	100	35	14	11	0	..	5	0	0
Berseem .	100	72	0	0	0	..	0	0	0
Barley .	100	..	75	50	..	31	..	..	6
Onions* .	100	71	51	40	16	..	9	3	6
Durra* .	100	82	84	73	68	..	25	19	0
Maize I .	100	89	92	67	64	..	43	24	0
Maize II.	100	..	83	56	54	..	28	28	17
Sugar-beet	100	59	..	60	54	..	37	29	19
Bermuda grass .	100	..	103	..	96	84	..	..	29

* Field experiment; all other experiments were carried out in the greenhouse at the Hebrew University.

These figures show that even with a salinity of 1,500 mg. Cl per litre, durra, maize, sugar-beet, and Bermuda grass give yields of over 50 per cent. of those obtained under normal conditions of irrigation. (It should be noted, however, that maize was harvested in the greenhouse as green-fodder.) The enormous salt-resistance of Bermuda grass is, of course, well known [6].

Nevertheless we hold that, under the climatic conditions of Palestine, no irrigation with so saline a water can be recommended, except perhaps for date palms and similar plants, since the salts tend to accumulate in the soil, and owing to the scanty rainfall they are not leached in the rainy season. The following figures, which could be amplified by many others,

show the salinization taking place during the vegetation period of 3–4 months:

TABLE 7. *Salinization of Soil at End of Vegetation Period*

Irrigation water containing Cl, mg. per litre	*Potatoes (greenhouse) Cl in soil (per cent.)*	*Durra (field experiment) Cl in soil (per cent.)*
160	0·04	0·03
500	0·09	0·04
750	0·18	0·07
1,000	0·28	0·10
1,500	0·33	0·23
2,000	0·30	0·33
2,500	0·34	0·45
3,500	0·49	0·73

Agricultural possibilities.—To-day barley is the most important crop, covering about 80 per cent. of the total area sown. Besides wheat, durra, water-melons, and beans are sown by the Bedouins. Agriculture seems to have been much more highly developed in antiquity [6]. The remains of ancient settlements and ancient cultivation found at various places should, however, not deceive us into exaggerating its importance. Such settlements were first and foremost caravan stations. For the growing population such caravan centres had naturally to provide storage facilities of water in order to render possible a modest cultivation of vegetables, &c. Although such storage facilities, terracing, and the skilful exploitation of run-off water from the hills may still excite our admiration we should nevertheless be careful not to be misled. In isolated cases the storage of run-off water may be possible, but an experiment undertaken by the Government of Palestine [7] in recent years proved to be a failure. On the Wadi Abu Samara, in the Beersheba plain, a dam was erected to intercept the water flowing off a catchment-area of 18 sq. km. Two million cubic metres of water fell on the catchment and 141,000 cu.m., i.e. 7 per cent., were impounded in the reservoir behind the dam. The bulk of this volume was impounded early in the season, but when needed for irrigation only 10,400 cu.m. were left, the rest having been lost by percolation and evaporation. So small an amount of water is, of course, of no practical value.

We therefore hold that, unless sweet water in economic quantities is struck, the agricultural future of the Negeb will have to be based on dry farming. This does not mean that the present methods of farming could not be considerably improved, but agriculture will primarily depend on the scanty amounts of rainfall. This rain should be conserved and care be taken that every inch of rain soaks into the soil. For this reason no run-off of water should be allowed. This aim can partly be achieved by terracing and contour-ploughing, but probably the most efficient method of rain-water storage in the Negeb is offered by the basin-listing method developed recently in the U.S.A. This method consists in building dams at intervals across the contoured furrows and so making reservoirs that are capable of holding the rain. Future experiments should mainly be carried out in this direction and only such

experimental work will show whether or not the Negeb is a suitable territory for Jewish colonization.

Acknowledgements

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SPRAY IRRIGATION

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WITH PLATE 9

Introduction.—The purpose of this paper is to describe a system of spray- or sprinkler-irrigation that has been developed on the Murrumbidgee Irrigation Areas, New South Wales, Australia, and to deal with the design and hydraulics of the system.

Under Australian conditions the advantages of overhead or spray irrigation over surface methods (i.e. those in which water flows over the surface of the soil) are:

1. Greater uniformity of irrigation and better control of amount of water applied. This especially applies to sandy soil of uneven contour where a uniform irrigation is particularly difficult if surface methods are used.

2. Where surface methods are used, grading of the land is necessary to a greater or lesser extent.

The fertility of the soil is reduced where the surface soil is removed in grading operations, and although the fertility is increased where the surface soil is dumped, this does not compensate for the loss in fertility where the soil is removed. Besides this, grading is an expensive operation. Spray irrigation obviates grading.

3. The ditches that are necessary for surface methods of irrigation occupy an appreciable proportion of the land. As ditches are unnecessary with spray irrigation, the land that would be occupied by ditches is occupied by the crop plants, and the working costs are actually less, as tillage operations are simplified and the cost of weed control is reduced. In sandy soils the seepage from ditches is also a serious problem.

Spray irrigation has, therefore, been found useful for orchards and vegetable crops on sandy, undulating land. Such crops produce a high revenue per acre, but are exacting in their irrigation requirements. Therefore, it pays to use a high standard of culture. The light, undulating soils are particularly suitable for these crops.

On the other hand, heavy flat land does not warrant the expense of spray irrigation. Uniform irrigation is a simple matter; little seepage occurs from the ditches and, as the irrigation-runs can be made quite long, relatively few ditches are required. Apart from these considerations, spray irrigation is unsuitable for heavy soils, as the rate of water absorption is too slow.

This is a broad, generalized summary of the relative merits of overhead and surface irrigation. For a particular crop, other considerations may also affect the issue.

Theoretical Discussion of Spray Irrigation

Hydraulics of water discharged from perforated pipes.—Spray-irrigation systems can be grouped into two main groups: those that distribute the water radially from sprinklers, and those that discharge the water from

perforations in long pipes. The system discussed here depends on the discharge of water from perforations in long pipes, which will be referred to as laterals.

In considering the design of such a system, we must investigate the hydraulics of water being discharged from perforations along a pipe when one end of the pipe is closed and the water at the other end is maintained at a constant pressure.

We start with two equations:

$$\frac{dQ}{dx} = B\sqrt{p}, \tag{1}$$

$$\frac{dp}{dx} = AQ^{1\cdot85} \tag{2}$$

Where Q = the quantity of water flowing across a section of lateral in gallons per minute,

p = pressure (in feet) of water at any point;

x = distance measured from the distal end (end farthest from main);

A = coefficient of friction loss defined by equation (2); and

B = coefficient of discharge per unit length of lateral defined by equation (1).

The above two equations have been shown to hold within the range of practical pressures.

From them we can deduce:

$$x = 0\cdot65926A^{-\frac{1}{2\cdot85}}B^{-\frac{1\cdot85}{2\cdot85}}\left[38P^{\frac{1}{38}} - \sum_{1}^{\infty} G_r P^{-\frac{[(3r-2)+(3r+1)1\cdot85]}{5\cdot70}} - 36\cdot4013\right]p_0^{\frac{1}{38}} \tag{3}$$

or $$x = 0\cdot65926A^{-\frac{1}{28\cdot5}}B^{-\frac{1\cdot85}{2\cdot85}}\left[38 - \sum_{1}^{\infty} G_r P^{-\frac{3r}{2}} - 36\cdot4013P^{-\frac{1}{38}}\right]p^{\frac{1}{38}} \tag{3a}$$

and $$Q = \left[1\cdot90\frac{B}{A}\left(1 - \frac{1}{P^{\frac{1}{2}}}\right)\right]^{\frac{1}{2\cdot85}} p^{\frac{1}{1\cdot90}} \tag{4}$$

where p_0 = pressure at distal end

$$P = p/p_0$$

G_r = the series term

$$\frac{1}{2}\cdot\frac{1}{3}\cdots\frac{1}{r}\cdot\frac{n}{n+1}\cdot\frac{1+2n}{n+1}\cdots\frac{(nr+r-1)2(n+1)}{(n+1)[(3r-2)+(3r+1)n]}$$

where $n = 1\cdot85$ (the exponential in equation 2).

The foregoing equations offer a complete solution to the problem, viz. the derivation of the pressure and discharge of water at any point along the lateral, for any length of lateral, coefficient of discharge or orifice, coefficient of friction loss, and pressure at the main or distal end when these quantities have been fixed.[1]

[1] For the derivation of these equations and discussion, see West and Howard: *The Design of Overhead Irrigation Systems*. Commonwealth Council for Scientific and Industrial Research, Australia, 1934, Pamphlet No. 50.

From these equations it follows that:

1. Near the distal end of the lateral, where the velocity of the water flowing in the lateral is very small, the change in pressure is negligible. As we proceed towards the pumping end the velocity of the water increases, and equation (2) shows that the rate of increase in the pressure increases the farther one proceeds from the distal end. In other words, the longer the lateral the greater the rate of fall near the pumping end (Fig. 1).

2. Changing the pumping pressure has practically no effect on the ratio of the discharge from any two points on the pipe. In other words,

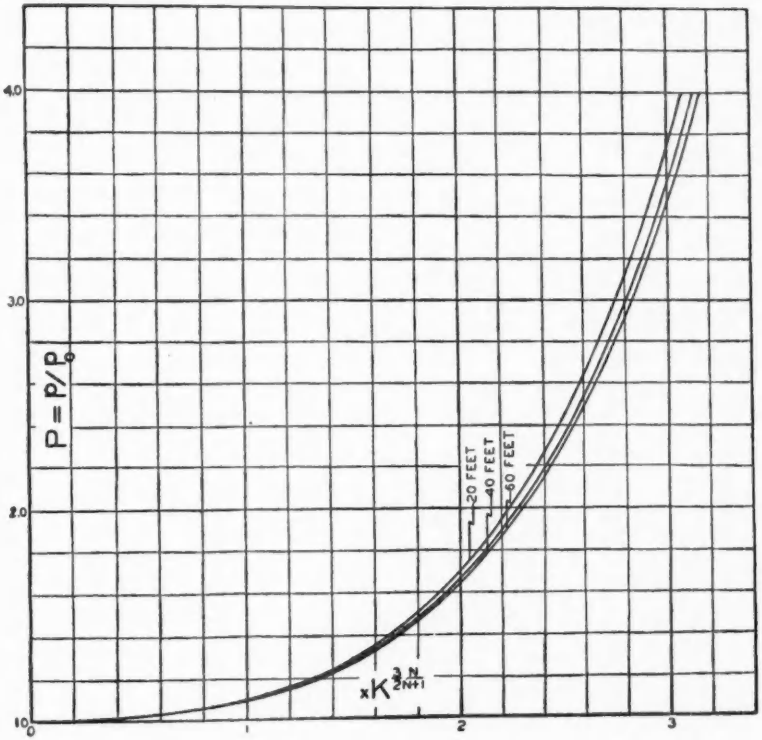


FIG. 1. Family of curves showing the relation between P and $xK^{\frac{3}{2}\cdot\frac{N}{N+1}}$ for various values of pumping pressure (expressed in feet of water).

one cannot correct excessive variation in discharge along the pipe by increasing the pumping pressure (Fig. 1).

3. The total discharge of the pipe is nearly proportional to the square root of the pumping pressure. [Compare the well-known relationship given in equation (1)].

Rate of application.—Theoretically, water can be applied to the land

as rapidly as the land will absorb it; but, as the practicable range of rates of application by spray irrigation (say between 0·25 and 2 in. per hour) is very small compared with the range that exists in the permeabilities of soils, we may say that for practical purposes land is either suitable or unsuitable for spray irrigation and, if it is suitable, the rate of irrigation will merely depend on considerations of cost.

Where the laterals are movable so that they can be used in different positions, the faster the water can be applied, within practical limits, the cheaper is the installation necessary to water any given area in a given time. Also, it will usually be found that the longer the lengths of lateral that are used the cheaper will be the installation. As both increasing the rate of application and increasing the length of lateral increase the value P, i.e. increase the variation in the quantity discharged along the lateral, one problem of design is to decide the most economical length of lateral and size of orifice that will not give an excessively high value of P.

Diameter of lateral.—It can be shown that if we increase the diameter of the lateral by the ratio r, the length of lateral available for a given value of P will be increased in the ratio $r^{1·737}$.

This and other points are brought out in Table I.

TABLE I

Diameter (Inches)	*x for a given P and B*	*P for fixed B and x*	*B and Q for fixed x and P*
$\frac{3}{4}$	0·411	ca. 7	0·254
$\frac{7}{8}$	0·537	4·1	0·405
1	0·678	2·37	0·551
$1\frac{1}{8}$	0·830	1·70	0·755
$1\frac{1}{4}$	1·000	1·40	1·000
$1\frac{3}{8}$	1·178	1·24	1·315
$1\frac{1}{2}$	1·370	1·13	1·630
$1\frac{3}{4}$	1·790	1·08	2·463
2	2·272	1·05	3·536

From column 2, for example, we find that if we had a $1\frac{1}{4}$ in. lateral of a given length, that applied water at a certain rate (in inches per hour) with any given fall-off in pressure, then using a 1 in. lateral the length must be reduced to 0·678 of the original length to apply water at the same rate without increasing the fall in pressure.

Column 3 illustrates the effect on the fall in pressure by using laterals of different diameter, but with the same sized orifices and same lengths. Thus, suppose a $1\frac{1}{4}$ in. lateral were of such a length and the orifices were of such a size that the ratio of the pressure at the two ends was $P = 1·40$, then with a 1 in. lateral of the same length and same-sized orifices the ratio P would be increased to 2·37.

Finally, if, as is usually the case, the length of lateral must be more or less fixed, due to consideration of the shape of the block to be irrigated, and the value of P is also fixed from considerations of the limit of variation in irrigation to be permitted, column 4 shows the relative rate at which water can be applied per unit area for laterals of different diameter. Thus, we can apply water at only about half the rate with a 1 in. lateral that we can obtain with a $1\frac{1}{4}$ in. lateral.

Pumping pressures.—As a variation in pressure does not affect the uniformity of irrigation, the pumping pressures used are decided largely by questions of costs. The higher the pressure the greater the power consumed; but the more rapid the application of water the lower the capital cost of the installation. Practical limits are the strength of the conducting system and the necessity for a certain minimum pressure to give a sufficient throw of water.

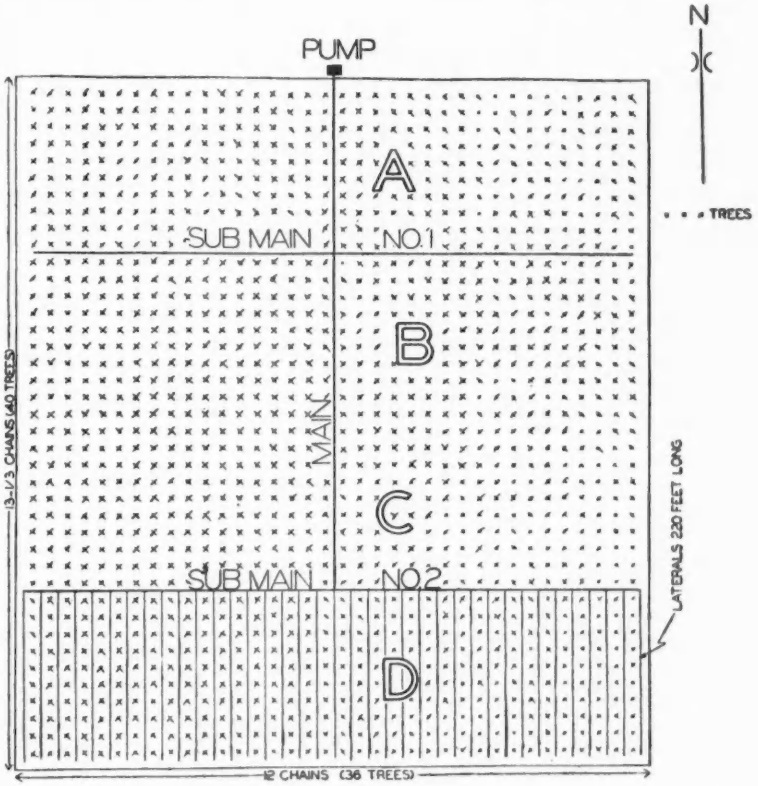


FIG. 2. Design of a spray-irrigation system in a hypothetical orchard showing lay-out of mains and laterals.

Practical Design of System

The practical design of a spray-irrigation system, such as is used on the Murrumbidgee Irrigation Areas, can best be illustrated by considering a hypothetical case.

Suppose we have a citrus orchard of 16 acres of trees planted on the square system 22 ft. apart, 40 trees+36 trees. We could adopt the arrangement shown in Fig. 2. In the figure the laterals are placed on the

south side of submain No. 2, between the rows of trees. The north ends of the laterals are connected to the submain and the southern ends are stopped with a cap. In this way, Section D can be irrigated. By pulling the laterals through to the northern side of submain No. 2 and connecting the south end to the submain and stopping the north end, Section C is irrigated. In a similar way sections B and A are irrigated successively from submain No. 1.

Construction of laterals.—The laterals are made of 1¼ in. downpipe, 26 gauge, joined end to end and soldered along the seams. They are perforated every 3 ft. with a small orifice, made simply by punching with an awl. The perforations lie in a straight line along one side and are elliptical in shape, the long axis of the ellipse being at right angles to the length of the lateral. As is well known, this leads to a fan-shaped jet, which spreads out in the same plane as the line of jets. (Plate 8.)

As illustrated in Plate 8*a*, the jets spread out and meet about 5 ft. from the lateral, having broken up into fine drops or a continuous spray. By twisting the lateral to revolve around its axis, the direction of the jets can be altered, and it is found that from three to five positions are sufficient to irrigate uniformly the 22-ft. strip.

In vegetable gardens the laterals can be placed overhead, say 6 ft. high, in permanent positions. In this case it is found that they will irrigate a 27-ft. strip and can be spaced this distance apart.

A 200-ft. length of lateral can readily be turned by hand from one end. The laterals are somewhat flexible and readily dragged over the land.

The best diameter to use is found to be 1¼ in., as with 1 in. laterals the fall in pressure, under most practical conditions, is excessive, whilst laterals of 1½ in. diameter are rather unwieldy in use and are more easily dented and damaged.

Calculation of discharge from laterals.—Suppose we wish to guard against an excessive fall-off in pressure and decide on a limit of 20 per cent. in the variation of rate of irrigation along the lateral, that is, the rate of discharge near the main must not exceed that near the distal end by more than 20 per cent. As the rate of discharge varies as the square root of the pressure, the percentage increase in pressure is approximately double that of the rate of discharge, so that the pressure near the main must not be more than 40 per cent. greater than that near the distal end, i.e. the ratio P must not exceed 1·4.

From equation (3) it can be shown that with laterals 220 ft. long and with orifices 3 ft. apart with a coefficient of discharge per orifice $B_3 = 0{\cdot}05$, $P = 1{\cdot}38$, and if we adopt a pressure of 40 ft. at the submain, it can be shown from equation (4) that the total quantity of water discharged from the lateral is 0·0554 cusecs, which is equivalent to 0·49 in. per hour (assuming a uniform irrigation over the 22-ft. strip).

The arithmetic in making these calculations is involved and tedious, and, therefore, tables have been published giving the desired information.[1]

[1] West and Howard: *A Note on the Hydraulics of a Spray-irrigation System*, Commonwealth Coun. Sci. and Ind. Res., 1938, vol. 11, no. 4.

The discharge from the orifice must be determined by direct trial, measuring quantity discharged from an orifice under a known pressure and applying the formula

$$B_3 = \frac{\text{quantity in gallons per minute}}{\sqrt{(\text{pressure in feet of water})}}.$$

As the orifices are 3 ft. apart, it will be noted that this coefficient B_3 is three times the coefficient B of equation (1), which refers to the discharge per foot of lateral.

An awl of correct size can then be made easily by trial and error. It is found that the coefficients of discharge from orifices made by the same awl do not vary much, and determining the discharges from six orifices is sufficient to calibrate an awl accurately.

The exact discharge from an orifice will depend on its shape, but to give an idea of the size of the orifices, it may be mentioned that the orifices made by an awl of elliptical cross-section such that the major and minor axes measured 94 thousandths and 47 thousandths of an inch, respectively, had a coefficient of discharge equal to 0·0544.

Mains and Fittings.—The mains and submains can be made of asbestos-cement pipes and placed underground. The laterals are connected to the mains through a short length of rubber hose, which is permanently attached to a standard of 1¼ in. pipe fixed to the submain. In an orchard these standards can come up under the drip of the foliage and so be out of the way of tillage implements. In this case the connecting length of rubber hose is long enough to reach to the lateral between the tree rows, i.e. about 12 ft. long. The connexion of the lateral to the hoses and the stopping of the distal end of the lateral can be done with appropriate threaded brass fittings. To obviate the expense of stopcocks the hoses connected to the submain not in use can be stopped with a threaded brass plug. Plate 9*a* shows the connexion of a lateral to a submain placed overhead. This submain is made of 22-gauge down-pipe; but this type of main is not recommended.

Pressure in mains.—In dealing with the laterals we adopted a pressure of 40 ft. in the submains. This has been found a useful pressure to use under practical conditions. A lower limit for the pressure at the distal end of the lateral is 25 ft., as below this pressure the jet has not sufficient throw. Probably with the use of stronger pipes for mains, such as asbestos-cement pipes, the working pressures could with advantage be greatly increased.

If we fix the pressure at the end of submain No. 2 at 40 ft. and allow a friction loss between the pump and this point of 20 ft., the total pumping pressure will be 60 ft., and the average friction loss will be 19 ft. per 1,000. As there will be 36 laterals discharging at once, the total discharge will be $36 \times 0{\cdot}0554 = 2{\cdot}0$ cusecs, so that the familiar formulae and tables for friction loss indicate an 8-in. main with submains beginning as 6-in. pipes and reducing progressively to, say, 2-in. pipes, as the quantity conducted diminishes.

It may be noted that by placing the laterals alternately in their positions in Sections A (connected to submain No. 1) and Section D (con-

nected to submain No. 2) for the first irrigation position, and then moving those in Section A progressively to Sections B, C, and D, and those in Section D progressively to Sections C, B, and A for the other irrigation positions, the quantity flowing through a submain can be halved, which will greatly economize in the initial cost of the mains. If this were done, a 6-in pipe could be used for the section of the main between the two submains, and the submains can begin as 4-in. pipe and progressively reduce to 2-in. pipe.

Further Illustrations of Design.—The above illustrates what would suit conditions on the Murrumbidgee Irrigation Areas, but supposing it were necessary to apply the water more uniformly, we could use a value of $B_3 = 0{\cdot}03$ which, for laterals 220 ft. long, would make $P = 1{\cdot}15$, i.e. only 7 per cent. more water would be applied near the submain than at the distal end, and with a 40-ft. head at the main, the water would be applied at the rate of 0·32 in. per hour.

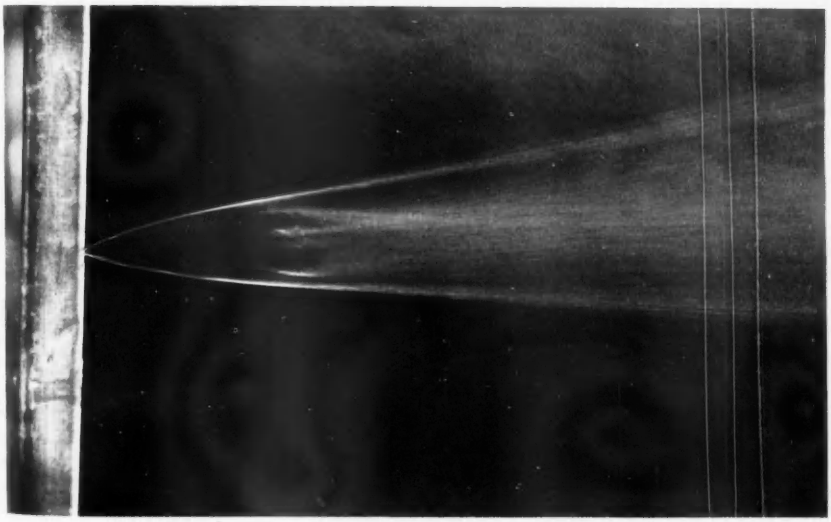
As a further illustration, we may suppose that there is no objection to a large variation in the irrigation. An orifice with $B_3 = 0{\cdot}10$ would apply the water at the rate of 0·8 in. per hour, but then we should have $P = 2{\cdot}57$; that is, the discharge near the main would be 60 per cent. more than that at the distal end.

Summary

A system of spray or sprinkler irrigation used on the Murrumbidgee Irrigation Areas, New South Wales, Australia, is described, and the hydraulic principles involved on water being discharged from a long perforated pipe are discussed, and their application is indicated.

(*Received May 3, 1939*)

a. Lateral in operation. (Note connexion to main at farther end)



b. Fan-shaped jet from elliptical orifice

EXPERIMENTS ON THE MANURIAL VALUE OF SEWAGE SLUDGE FROM SEPTIC TANKS

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Introduction.—The introduction during last century of sewage-disposal works as a necessary social advancement in the life of the towns and large villages of Great Britain, focused the attention of agricultural scientists on the enormous loss in plant nutrients which would result from such modern methods of sanitation and disposal of human excreta, unless some means of utilizing this material could be devised. From time to time suggestions and attempts have been made to treat sewage in ways that would render the plant nutrients in it available for use as fertilizer, but the efforts made have, on the whole, not been entirely successful.

At many sewage-disposal works, considerable areas of land are available and by flooding this land periodically with sludge from septic tanks and thereafter cropping with suitable economic plants, considerable use is made of the products of sewage-treatment, but in many towns the area of land available is very limited, so that other outlets for the sludge have to be found.

Former investigations.—Early in the present century a Royal Commission was appointed to investigate the question of sewage disposal, and the appendix to the commissioners' report deals with the manurial value of sewage sludge. The chief concern, apparently, was related to the use of land for sewage purification, and in this connexion the possible value of sludge as a manure was considered. Opinions regarding this value were not unanimous, and as a result the commissioners decided to institute experiments to investigate the question. With the co-operation of the Board of Agriculture and Fisheries, field experiments were laid down at five centres on arable land, and at eight centres on grassland. Results were obtained for one season only (1905). In addition, the Woburn Experimental Station carried out pot-culture experiments. Sewage sludge from septic tanks, artificially dried, was used at all centres, and comparisons were made with concentrated fertilizers. A full account of these experiments appears in the 5th Report of the Royal Commission on Sewage Disposal (also in Appendix 8 to the 5th report and in the appendix to the 9th report). Detailed summaries of the experiments were given in the *Journal of the Board of Agriculture* [1, 2]. It was concluded that the action of the nitrogenous and phosphatic constituents of the sludge was very slow as compared with the effect produced by these plant nutrients in ordinary concentrated fertilizers. It was also considered that much larger dressings of the sludge should have been used, and that this material would be likely to give better results when used on permanent grassland than on arable crops, owing to the relative unavailability of the essential constituents. From the results of the pot experiments, Voelcker concluded that the artificially dried sludge was worth about 10*s.* per ton on the land.

XUM

At a later date (1913–14) further experiments were carried out at Rothamsted and Woburn, using a degreased sludge, as it was thought that the presence of grease might retard decomposition of the organic matter and the availability of the manurial constituents. The results from these experiments were very disappointing, probably because the season was a distinctly dry one. The question of sewage treatment and availability was further discussed a year later in an article by Gladys Mumford [3], and there is a reference to the use of sewage sludge as a fertilizer in the same journal [4] under 'Notes on Manures', which suggests that, as a result of the unsatisfactory results from experiments then available, farmers were not favourably disposed towards this material.

H. J. Page, in an article on the utilization of waste products in agriculture [5], pointed out that great public service would be rendered if methods for sewage disposal could be devised 'which would be both hygienic and at the same time not agriculturally wasteful,' and Garner [6] stated that wet sludge is exceedingly difficult to handle, finding no favour with farmers, its value lying as much in the physical effects of large dressings applied as in the fertilizing action of its constituents. About four years later, E. H. Richards [7] briefly reviewed the position regarding the use and value of sewage sludge as a manure.

Summing up all these reports, one would be justified in coming to the conclusion that sewage sludge is of little use as a fertilizer and hardly worth consideration by farmers and market-gardeners. It should be noted, however, that the great majority of the experiments and observations referred to were expressly concerned with *the value of sewage sludge as an alternative to concentrated fertilizers and not as a substitute for farmyard manure.*

A new situation has arisen in the last twenty to thirty years owing to the reduced quantities of dung produced in this country. Organic manure forms the basis of arable-crop production, and therefore more and more attention is being directed to the finding of substitutes for dung that will give comparable crop results. Market-gardeners and allotment-holders have been particularly hard hit by this shortage, since, in the past, they have relied largely on the stable manure from towns. Sir John Russell has stated quite recently [8] that shortage of cereal straw and decrease in winter-feeding of bullocks have resulted in a serious curtailment in the supply of organic manure for the soil. He stresses the necessity for considering alternative sources of organic fertilizers and mentions that sewage sludge amongst other materials still offers possibilities. Many growers, including farmers as well as market-gardeners and allotment-holders, have turned their attention in recent years to local supplies of sewage sludge, and nowadays the questions frequently asked are: Is this material of any use as an organic manure? Is it worth the cost of cartage and application to the land?

Such questions were put to the writer in 1934 by horticultural advisers in the Midland area, and, in view of the rather unsatisfactory evidence resulting from the 1905 and subsequent experiments, it was decided to investigate the composition of local supplies of sewage sludge, and by

means of field experiments to compare the manurial value of sludge with that of farmyard manure. The results of this investigation are recorded below.

The Composition of Sewage Sludge

Visits were made during 1935 and 1936 to several sewage-disposal works, situated in Midland towns and having a population not exceeding 50,000, i.e. where simple methods of treatment and disposal are being practised. Towns of this size are surrounded by market-gardens and allotments, and as carriage distances are short, it was felt that a potential demand existed for this material if its use could be justified.

Samples of sludge were obtained and analysed. The results are given in the Appendix.

Although considerable variation in composition, as shown in the Appendix, is bound to occur with a material of this kind, one can state that the great bulk of ordinary sewage sludge as produced in septic tanks and then 'lagooned' has a composition falling within the following limits:

	Per cent.
Moisture	50–80
Organic matter (loss on ignition)	10–30
Total nitrogen	0·5–1·0
Phosphoric acid (P_2O_5)	0·1–0·5
Potash (K_2O)	0·03–0·3
Ether-soluble matter	1–9

The fresh material as dug out of the lagoons is very sticky, owing to the high percentage of colloidal matter. On storage in heaps, however, the moisture-content diminishes, and the material gradually becomes more tractable. To observe any changes in composition during storage, a heap of several tons was sampled periodically over a period of two years, and the figures obtained are given in Table 1.

TABLE 1. *Composition of West Bridgford Sewage Sludge*

Dug out of lagoon in Nov. 1936. Fifty-ton heap

	As sampled		*On dry matter*	
	Moisture	*Org. m.*	*Total* N	*Org. m.*	*Total* N
April 1937	67·6	18·2	0·66	56·2	2·0
Sept. 1937	41·5	28·3	1·51	48·4	2·6
March 1938 (*a*)	51·5	21·2	0·84	43·7	1·73
(*b*)*	20·9	34·2	1·77	43·2	2·24
Oct. 1938	54·4	19·8	1·16	43·4	2·55

* Dry material from outside of heap.

These results show that the moisture-content fell roughly by 50 per cent. during the two years, and thereafter tended to remain constant; the loss of organic matter was not serious; the total nitrogen-content fluctuated considerably, but there is no indication of serious loss during the two years. Longer periods of storage, however, may cause a loss of nitrogen.

In 1937 two samples were taken at Southwell Sewage Works, one from

an old dump at least six years old, and the second from a heap dug out of a lagoon six months previously. Results of analysis are as follows:

	Moisture	*Org. m.*	*Total* N	*On dry matter*	
				Org. m.	*Total* N
Old sludge	40·6	18·3	0·74	30·9	1·25
New sludge	60·3	19·2	0·96	48·3	2·42

Although the two samples are not strictly comparable since the initial composition of sludge is likely to vary considerably from time to time, yet the variation in nitrogen percentage on dry matter is so marked as to suggest that storage for several years may cause serious loss of this valuable constituent.

Owing to its great variability in composition, it is difficult to compare sewage sludge with that of other organic manures, but the following rough comparison may be taken as a guide to the practical results which one might hope to obtain under field experimental conditions.

	Average composition	
	Sewage sludge (12 samples)	*Farmyard manure**
Moisture . . .	70	76
Organic matter . .	19	..
Nitrogen . . .	0·78	0·64
Phosphoric acid . .	0·31	0·23
Potash	0·12	0·32

* *Fertilizers and Manures*, A. D. Hall, 1st ed., 1909, p. 205.

In view of the similarity of the above figures—with the exception of potash—it was decided to carry out field experiments comparing equal weights of farmyard manure and sewage sludge, both being supplemented with artificial fertilizers.

Field Experiments

County Institution Gardens, Basford, Notts.

The soil in these gardens is a very light sandy loam of the Trias (Bunter) formation. It is freely drained and non-retentive of moisture, crops thereby suffering in periods of rainless weather.

Experiments in 1935

A 16-plot Latin square was laid down, each plot being 1/50 acre. Potatoes—variety Arran Banner—was the selected crop. Manurial dressings, per acre, were as follows:

Plot 1. Dung, 15 tons; artificial fertilizers, 10 cwt.
Plot 2. Sewage sludge, 15 tons; artificial fertilizers, 10 cwt.
Plot 3. Artificial fertilizers, 10 cwt.
Plot 4. Control (no manure).

The mixture of artificial fertilizers consisted of two parts each of sulphate of ammonia, sulphate of potash, steamed bone flour, and four parts of superphosphate.

Trenches were made by hand, and the weighed quantities of dung and sewage sludge were distributed evenly in them. The 'artificials' were then spread along the trench and the potatoes planted.

Marked differences in vigour of tops were noticed during the season, Plots 1 and 2 standing out in contrast to Plots 3 and 4. The weather was very variable: February, April, June, and September were wet months, rainfall being well above the average; March, May, July, and August were very dry. Temperatures on the whole were favourable, but there were a few very cold spells during the growing-season.

Mean Yields of Potatoes (*cwt. per acre*)

Plot 1	133·1
Plot 2	134·6
Plot 3	115·4
Plot 4	98·5
General mean	120·5
Standard error	±2·5

The difference in yield between Plots 1 and 2 was not significant, but both treatments gave highly significant increases in yield over the 'artificials only' and 'no manure' plots.

Experiments in 1936

To ascertain the residual effect of the manuring, the plot area was dug twice during the winter, carrots were drilled in the spring and the crop lifted and weighed in November. No visible differences in growth were observed during the season. The plant was rather uneven, there being many gaps in the rows, and, as a result, the experimental error was rather high.

Mean Yields of Carrots (*cwt. per acre*)

Plot 1	182·6
Plot 2	174·4
Plot 3	161·0
Plot 4	149·8
General mean	166·1
Standard error	±10·6

The difference in yield between Plot 3 and Plots 1 and 2 was small and not significant, thereby indicating very little residual value in the second season on this type of soil from either the dung or the sewage sludge.

In 1936 the experiment with potatoes was repeated as in 1935, not only at the Basford centre but also at Southwell and Mansfield. At all three centres the layout and manuring described under the 1935 Basford experiment were followed, but at Basford and Southwell the size of the plots was halved, i.e. 1/100 acre. Arran Banner seed was planted at all centres. In each case local supplies of dung and sewage sludge were used.

Rainfall in the Midlands was above the average in February, June,

July, and September, but rather deficient in March, April, and May. Temperatures were above average in May, June, August, and September. On the whole, it was a good season for crop growth.

County Institution Gardens, Basford, Notts.

A plot of land adjacent to that used for the 1935 trial was selected, but this land was in a more fertile condition, having been dunged and dressed with 'artificials' each year for the previous four years.

The crop on the plots receiving dung was decidedly more vigorous than that on either of the other sets of plots, the plots treated with sewage sludge being a good second. These differences were reflected in the yield figures.

County Institution Gardens, Southwell, Notts.

The soil here is a medium loam, alluvial drift over Trias (Keuper marl). The gardens are low-lying and subject to flooding, hence the soil is inclined to be wet in rainy periods. The area selected had not received dung or artificial fertilizers for the past twelve years.

Throughout the season the plots treated with sewage sludge looked far superior to the dung, 'artificials only', and 'no manure' plots. Disease appeared late in the season and affected the crop over the whole of the plot area.

County Institution Gardens, Mansfield, Notts.

These gardens lie on the junction of the Trias and Permian, the soil being a light loam, mainly derived from the lower beds of the Bunter sandstone. Drainage is free. The area selected had been reasonably well manured in recent years with both dung and artificials.

During the growing-period, the plots receiving dung produced more vigorous tops than the other treatments, whilst the sewage-sludge plots always looked superior to the 'artificials only' or 'no manure' plots, the latter carrying a poor crop.

TABLE 2. *Mean Yields of Potatoes (cwt. per acre) at the Three Centres*

	Basford	*Southwell*	*Mansfield*
Plot 1	253·8	244·0	177·6
Plot 2	197·8	269·4	156·7
Plot 3	144·6	215·4	87·6
Plot 4	67·4	117·4	35·4
General mean . . .	165·9	211·5	114·3
Standard error . . .	±6·7	±6·0	±8·9

Thus, at all three centres good yields were obtained on Plots 1 and 2 and at the Southwell centre on Plot 3 as well. At Basford the yield from dung was significantly higher than that from sewage sludge; at Southwell, this position was reversed, whilst at Mansfield, the yield from dung, although higher than that from sewage sludge, was not

significantly higher. In all cases the crop on plots receiving artificials only was markedly and significantly lower than that from Plots 1 and 2, whilst the control plots at all centres amply demonstrated the low yields which resulted from the unmanured soil. It is suggested that the variation in the effect of the sewage sludge at the three centres, as compared with the effect of the dung, may have been directly related to the moisture-content of the soil and thereby also to the rate of decomposition of the sludge. It is clear, however, that the sewage sludge at all centres had a marked effect on the crop yield.

Experiments in 1937

For this season it was decided to carry out another trial on potatoes at the Basford centre, but to vary the manurial dressings. The size of plots and layout were the same as for the previous year, but manurial application (per acre) were as follows:

Plot 1. Dung, 15 tons; artificial fertilizers, 10 cwt., composition as in previous experiments.
Plot 2. Sewage sludge, 15 tons; artificial fertilizers, 10 cwt., composition as in previous experiments.
Plot 3. Sewage sludge, 25 tons; artificial fertilizers, 5¼ cwt., consisting of 2 cwt. superphosphate, 1 cwt. steamed bone flour, 1½ cwt. sulphate of potash, and ¾ cwt. sulphate of ammonia.
Plot 4. Artificial fertilizer only, 16 cwt., consisting of 6 cwt. superphosphate, 3 cwt. steamed bone flour, 4 cwt. sulphate of potash, and 3 cwt. sulphate of ammonia.

Arran Banner seed was again planted.

The weather was very different from that of the previous two years. After excessive rainfall in February, March, and April, dry weather was experienced during May, June, July, and August. These long spells of dry weather, which predominated during the growing-season, very badly affected crops growing on sandy land of the type found at Basford, and, as a result, the crop yields were disappointingly low.

Mean Yields of Potatoes at Basford (*cwt. per acre*)

Plot 1	57·1
Plot 2	27·0
Plot 3	23·0
Plot 4	37·9
General mean	36·3
Standard error	±6·8

The yield from the dunged plots was significantly higher than that from the sewage-sludge plots, that from the 'artificials only' plots was higher but not significantly higher than the yields from Plots 2 and 3. Undoubtedly the lack of moisture prevented decomposition of the sludge and release of nitrogen.

At Southwell, to ascertain the residual effect, if any, of the manurial dressings, the plot area of the previous year was dug over and swedes drilled in the spring.

Mean Yields of Swedes at Southwell (cwt. per acre)

Plot 1	87·5
Plot 2	103·1
Plot 3	66·7
Plot 4	58·3
General mean	78·9
Standard error	±4·2

These figures follow those obtained from the previous year's potato crop, the sewage sludge still showing a significant increase in crop over the dung-dressed plots, whilst both were still significantly higher than either the 'artificials only' or the control plots. At this centre a series of plots, manured on similar lines to those at Basford, was laid down and carrots sown. The crop came up very unevenly and owing to the poor and gappy plant, this experiment was abandoned.

Experiments in 1938

For this season, experiments on carrots and onions were selected, the former at Basford and the latter at Southwell. The carrot plots, as in the previous year at Southwell, were a failure owing to uneven plant. Carrots appear to be an exceedingly difficult crop to grow on small experimental plots. The onions germinated rather unevenly, and at thinning time the numerous gaps were filled with transplanted plants. These, however, failed, as one would expect, to catch up with those which had grown through from seeding, and, as a result, the experimental error was high. Manurial dressings, per acre, were as follows:

Plot 1. Sewage sludge 30 tons, superphosphate 1 cwt., sulphate of potash 2 cwt.
Plot 2. Sewage sludge 15 tons, superphosphate 2 cwt., sulphate of potash 2 cwt.
Plot 3. Superphosphate 3 cwt., sulphate of potash 2 cwt., sulphate of ammonia 1½ cwt.

Plots were 1/200 acre. Manures were forked in a few weeks before onions were drilled. The sludge used for this experiment had been dumped at the West Bridgford works the previous year and was partially rotted. Distribution was comparatively easy, but it is to be regretted that it was not possible to have this manure distributed and forked in earlier in the year. As expected, the time between application and crop growth was too short for adequate decomposition of the sludge, and this was badly hindered by a very dry spring.

Mean Yields of Onions at Southwell (cwt. per acre)

Plot 1	194·6
Plot 2	189·1
Plot 3	214·8
Plot 4	178·0
General mean	194·1
Standard error	±7·9

Plot 3—artificials only—gave a yield significantly higher than Plot 2—15 tons per acre sludge with artificials—indicating the effect of the dressing of sulphate of ammonia, in contrast to the unavailability of the nitrogen in the sludge.

General Observations on Experiments

The sewage sludge gave the most favourable results at the Southwell centre and the least favourable at Basford, the one experiment at Mansfield showing an intermediate effect. Although a rigid comparison is difficult, sewage sludge and dung from different sources having been used, yet it does appear feasible to attribute the effectiveness of the sludge to the degree to which this substance is decomposed before the crop is grown. Soil moisture appears to have an important effect on rate of decomposition.

It is suggested therefore that, under favourable conditions, sewage sludge may be as effective as dung, but if conditions are adverse, militating against rapid decomposition, then dung has a distinct advantage over the sludge.

These experiments suggest, moreover, that sewage sludge can be usefully employed as a substitute for dung, and, given reasonably normal climatic conditions, its use would be justified and an increased yield for a crop like potatoes, or possibly cruciferous crops, could be confidently expected. For market-garden crops, like carrots, onions, beet, and peas, one would suggest that the sludge should be dug in some months before sowing, and the ground dug over a second time to assist distribution of the manure throughout the soil.

The colloidal sticky nature of sewage sludge renders it more difficult than dung to dig or plough into the soil. With potatoes, however, the material can be spread in the bottom of the trench. Ample moisture is necessary for decomposition. In more than one instance, lumps of partly decomposed sludge were visible during the winter following a dry summer. It should be pointed out, however, that similar aggregates of dung were also noticeable.

In no case was any deleterious effect due to the presence of greasy matter noticed.

Additional Notes on the Use of Sewage Sludge

The works at one town in Nottinghamshire is now experiencing not the slightest difficulty in disposing of its output of sludge. Some ten years ago the sludge could only be disposed of by giving it away, but at the present time, 1*s.* 6*d.* per load ex works is easily obtainable, and many clients are unable to obtain the quantities desired.

At another town—on the sea coast—the gardens on the promenade, which have a soil mainly composed of sand, have been turned into excellent rose gardens and herbaceous borders, by the incorporation of large quantities of sewage sludge with the sand. The surveyor relies on this material for the maintenance of the fertility of the public gardens.

A large potato-farmer in Lincolnshire, whose land adjoins a sewage-disposal works, has used this material for the past five years, his consumption being about 800 tons per annum. The soil on his farm is a stony chalky boulder-clay, and this receives about 15 tons per acre of sludge for the potato crop every four years. It is carried on to the fields in summer and heaped, preparatory to spreading, on the stubbles in the

autumn, when it is ploughed in. This farmer considers that the sludge which he uses has a value about two-thirds that of best covered-yard dung.

Some years ago the writer was asked to advise on the improvement of a school playing-field which had been seeded down on a gravel subsoil and was in a very poor and worn-out state. Old, well-rotted sewage sludge was applied in the winter at a rate of 30–40 tons per acre and the field harrowed several times. A luxuriant herbage resulted in the spring, and the field has now been quite satisfactory for many years.

Conclusions

1. It is suggested that the experiments and observations contained in this paper indicate that sewage sludge produced by the ordinary process of digestion in tanks and draining in lagoons—as practised in many small sewage-disposal works—has a considerable value as a basal organic manure and should prove quite satisfactory as a substitute for dung, rather higher dressings being used than of cake-fed dung. It must be understood, however, that to obtain good results adequate dressings of artificial manures must also be applied.

2. It has been observed that decomposition of fresh sewage sludge may be slow during dry periods, particularly on light land, since adequate moisture is necessary for fairly rapid decomposition. The heaping of sludge for a year or two, or even composting with soil, materially improves the utilization of this manure by producing a more friable material which can be distributed more evenly, and decomposition rendered more rapid.

3. There is some evidence that on certain soils an appreciable residual manurial value may accrue in favour of the second year's crop.

4. There appears to be no reason to suggest that the greasy matter contained in sewage sludge is likely to prove detrimental to the soil texture, provided of course excessive quantities are not applied at short intervals.

Acknowledgements

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APPENDIX

Analysis of Sewage Sludge from Lagoons

Date of sampling	*Reaction to litmus*	*Percentage composition of original material*						*Per cent. loss of N on air-drying*
		Moisture	*Organic matter*	*Total* N	*Total* P_2O_5	*Total* K_2O	*Ether-extract*	
West Bridgford								
Dec. 1932	Faintly acid	74·0	15·7	0·68	0·15	0·06	1·26	Nil
			60·5	*2·62*	*0·58*	*0·23*	*4·85*	
May 1933	Alkaline	67·3	24·7	0·83	0·28	0·09	1·66	3·5
			75·5	*2·54*	*0·87*	*0·28*	*5·09*	
Mar. 1936	Alkaline	70·5	13·0	0·76	0·18	0·28	1·21	6·6
			44·1	*2·59*	*0·61*	*0·95*	*4·10*	
Apr. 1937	Neutral	67·6	18·2	0·66	0·32	0·08	0·46	Nil
			56·2	*2·03*	*1·02*	*0·26*	*1·42*	
Mansfield								
Dec. 1932	Faintly acid	83·6	11·2	0·52	0·15	0·06	2·90	1·25
			68·6	*3·19*	*0·92*	*0·36*	*9·56*	
Dec. 1932	Faintly alkaline	74·4	11·9	0·53	0·18	0·09	1·14	7·55
			46·1	*2·07*	*0·70*	*0·36*	*4·45*	
May 1933	Faintly acid	70·0	20·9	0·86	0·32	0·10	1·43	Nil
			69·6	*2·87*	*1·06*	*0·33*	*4·75*	
May 1933	Faintly acid	70·9	20·8	0·80	0·38	0·06	1·16	Nil
			71·6	*2·76*	*1·30*	*0·21*	*3·97*	
May 1933*	Neutral	70·8	17·7	0·58	0·47	0·08	1·03	Nil
			60·0	*1·99*	*1·60*	*0·27*	*3·51*	
Apr. 1936	Alkaline	67·9	16·5	0·86	0·33	0·19	1·50	12·6
			51·4	*2·68*	*1·04*	*0·58*	*4·67*	
Kirkby-in-Ashfield								
Dec. 1932*	Neutral	73·9	18·2	0·63	0·26	0·03	2·15	Nil
			69·9	*2·42*	*1·01*	*0·12*	*8·16*	
May 1933	Neutral	62·1	31·4	1·08	0·45	0·08	2·99	Nil
			82·8	*2·87*	*1·18*	*0·22*	*7·90*	
Southwell								
Mar. 1936	Neutral	52·7	26·0	1·05	0·52	0·29	2·40	3·8
			45·2	*2·21*	*1·10*	*0·62*	*5·06*	
Apr. 1937*	Neutral (1)	43·4	19·7	0·73	0·84	0·11	0·47	Nil
			34·9	*1·27*	*1·48*	*0·19*	*0·83*	
Jan. 1937*	Neutral (2)	40·6	18·3	0·74	0·93	0·12	0·52	Nil
			30·9	*1·25*	*1·56*	*0·20*	*0·87*	
Jan. 1937*	Neutral (3)	60·3	19·2	0·96	0·66	0·11	1·14	Nil
			48·3	*2·42*	*1·65*	*0·28*	*2·86*	
Buxton								
Sept. 1933	Strongly alkaline†	59·2	22·6	1·19	0·22	0·07	1·18	16·4
			55·3	*2·93*	*0·51*	*0·17*	*2·90*	
Skegness								
Oct. 1933	Acid	82·5	12·7	1·42	0·24	0·21	1·41	54·5
			73·2	*8·52*	*1·26*	*1·21*	*8·05*	
Oct. 1933	Acid	80·4	18·3	1·97	0·28	0·15	1·10	58·4
			93·2	*10·02*	*1·44*	*0·79*	*5·58*	
Jan. 1934	Strongly acid‡	91·7	6·2	0·64	0·12	0·09	0·40	54·1
			74·8	*7·73*	*1·44*	*1·14*	*4·84*	
Jan. 1934	Amphoteric‡	91·2	6·3	0·77	0·12	0·09	0·46	62·2
			71·6	*8·76*	*1·37*	*0·99*	*5·20*	
Jan. 1934	Slightly alkaline	92·3	5·4	0·76	0·19	0·12	0·47	65·8
			69·7	*9·83*	*2·46*	*1·55*	*6·08*	
Apr. 1934	Slightly alkaline	86·2	10·0	0·60	0·30	0·06	0·71	1·7
			72·1	*4·34*	*2·15*	*0·10*	*5·23*	
Apr. 1934	Slightly acid	76·8	15·7	0·79	0·30	0·45	1·14	2·6
			68·6	*3·45*	*1·30*	*0·43*	*4·97*	

The figures in italics give the percentages on dry matter.

* Samples taken from dumps. Mansfield five years old; Kirkby-in-Ashfield several years old; Southwell 1 and 3, six months old; 2, seven years old.

† This sludge had been treated with lime and filter-pressed.

‡ These sludges became alkaline during air-drying.

VARIABILITY OF PLOTS OF VARIOUS SHAPES AS AFFECTED BY PLOT ORIENTATION

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Previous Work

IN 1931 the author pointed out [1] that, from theoretical considerations, corroborated by ample experimental evidence, it might be concluded that the shape of plot constituted an important means of controlling soil heterogeneity, and that in no case could square plots sample the soil conditions better than long and narrow ones. Hence the smaller the value w/l (width over length of a plot), the more uniform will be the plots of an experiment. However, care should be taken to avoid the effect of competition, greatly increased in the case of long plots, and variability due to causes other than soil heterogeneity (for example, in accurate measurement of the width of the plots, former paths, drainage-pipes, the furrows left after ploughing, irregular sowing of individual rows).

Since then very many experiments have been reported having as their object the determination of the best shape to be adopted in field experimentation. Justensen [2] concluded that 'long and narrow plots are more efficient than shorter and wider of the same size', and Kalamkar [3] that 'the superiority of long and narrow plots over shorter and wider ones is demonstrated'. Reynolds *et al.* [4] found that 'The shape of plot had no significant effect on the variability at College Station, but long, narrow plots were less variable than short, wide plots of the same size at Chillicothe. In general, long, narrow plots are to be preferred'. Pan [5] got contradictory results in China: 'Increase in the width of plot was comparatively more efficient than increase in length of row in the experiments at Hangchow, but an opposite result was obtained at Wufu.' Hutchinson and Panse [6] stated that 'plot shape was found of most importance within the range of plot sizes usually employed in field experiments (1/100 acre and larger), particularly with small ratios w/l'. It is worth noticing, however, that with exceedingly small plots (1/2,000 to 1/125 acre) there was no appreciable advantage in favour of the long plots. The data produced by Bose [7] indicate that long, narrow plots are less variable, probably because soil fertility was shown to vary along the plots. Loesell [8] also found that 'increasing the size of the plot by increasing its length proved much more effective in reducing the standard error in percentage of its mean, than making a similar increase in plot size by increase in width'. Similar conclusions were reached by Kulkarni and Bose [9], who summarized their results as follows: 'Highly narrow strips of plots lead to greater precision than plots of same area but much wider and not so narrow. . . . The results of all three years corroborate Christidis's conclusions'; also by Sayer *et al.* [10], who showed that 'long, narrow plots are thus found to sample the soil best,

and this tallies with the conclusions reached by Christidis'. In another case Sayer and Iyer [11] concluded that 'the error can only diminish to a slight extent by a w/l ratio up to a limit of 30. In practice, however, it is convenient to adjust the size of plots in such a way as to have the length 5 to 15 times the breadth.' Smith [12] states that 'it appears theoretically inevitable that shape of plot should have some effect (on the correlation between adjacent areas). . . . The importance of plot shape is of course particularly accentuated in fields which show differential directional heterogeneity.' From his own data, however, he found that there was no consistent change of variability, relative to shape of plot. Nevertheless, 'it does appear that long narrow plots tend to be on the average less variable than square plots, a finding which agrees with the observation that adjacent areas tend to be more closely correlated than most distant areas'. Finally, Macdonald *et al.* [13], working with cotton at Barberton, South Africa, found a rapid decrease in the standard error as the plots lengthened, showing that the efficiency of their experiments increased as the plots became narrower and shorter.

On the other hand, Thompson [14] found that long, narrow, single-row plots had a significantly larger standard deviation than almost square multiple-row plots. 'It is safe to assume', he concluded, 'that much of the reduction in variation in favour of the square plots was due to the number of rows included within the plots, indicating that variation existed between rows and was probably due to factors other than soil heterogeneity. . . . Where a difference has been found, it has been in favour of the long plots. Long narrow plots running across the direction of the rows probably would have given still less variation than was obtained with the plot arrangement used.'

Similarly, Wiebe's data [15] appear to suggest that square plots are more uniform than long narrow ones along the rows of the experiment. He concluded that 'the variation within combination plots compounded by contiguous association decreases when the size is constant but the shape approaches a square'. A close examination of his data, however, shows that, as in the previous case, the variability of whole rows is undoubtedly affected by causes other than soil heterogeneity. For instance, all the 12 series of row 3 gave without exception a higher yield than the corresponding series of the adjoining row 4. Also the yield of all series of row 10 are smaller than those of row 11, which are again higher than those of row 12. Such cases are not uncommon in Wiebe's data, and this is entirely incompatible with the effect of innumerable and uncontrollable random factors governing soil heterogeneity.

The evidence accumulated in this respect since 1931 supports, in the great majority of cases, the view that soil heterogeneity can be significantly reduced by the use of plots as long and narrow as practically possible. The underlying theoretical principles developed elsewhere [1] do not seem to have been invalidated by any of the work subsequently published. However, although the question of the orientation of plots was there fully discussed from a theoretical point of view, no experimental evidence was then available to show that long and narrow plots were always more efficient than square ones in controlling soil hetero-

geneity. Some of the authors previously mentioned (for example, Smith [12]) seem to hold the view that long narrow plots may be less uniform than square ones, depending upon their orientation in the field. In order to investigate this point, as well as to provide additional evidence regarding the effect of the shape of plot, a suitable experiment was devised in 1938 and carried out at Sindos by the Greek Cotton Research Institute.

Lay-out of the Experiment

Four blocks were laid out according to the general arrangement illustrated in Fig. 1. Two of them (A and D) were orientated at right angles to each other, whereas the other two (B and C) were given intermediate orientations (30° and 60° from A and D blocks, respectively). Each block consisted of 20 rows one metre apart and 66 m. long. Two of the rows, however, on each side of every block and one metre long at each end of the rows were rejected to eliminate border effect. Consequently, each block finally contained 16 rows, each 64 m. long.

Sowing took place on April 30, 1938, under favourable conditions. All the blocks were drilled by a Cole No. 41 cotton-planter and with a pure line (selection 13X4) bred from the local stock. The germination of the seed and the subsequent development of the plants were very satisfactory. As soon as the stands of cotton were definitely established each row was divided into 4-metre lengths, the produce of which was eventually picked and weighed separately. Consequently each row provided 16 ultimate units (4 sq. m. in area) and each block 256 such units, the whole experiment (4 blocks) including 1,024 units.

All 4 blocks were treated as an ordinary cotton field, the hoeing, thinning, irrigation, &c., taking place in the usual way. The crop finally proved to be a great success. Although no manure of any kind was applied, the average yield obtained reached 250 kg. of seed-cotton to the stremma (= 1,000 sq. m. or 1/4·0468 acre), or exactly 1½ bales of lint to the acre. All the conditions during the growing-season were absolutely normal and the weather at picking-time was so favourable that not a single boll was left on the plants unopened.

The yields obtained for each of the 1,024 units are given in Table 1 (A, B, C, and D). These data were used to construct a fertility contour map (Fig. 1), in the following way: the yields of four adjacent sections (sections no. 1 of rows 1+2+3+4, 5+6+7+8 . . ., sections no. 2 of rows 1+2+3+4, &c.) were added and their sum taken as the productivity at the centre of the rectangular plots thus formed (4×4 m.). The contour lines were then traced at fixed intervals by interpolation.

After the leaves started falling in autumn, the numbers of plants per unit were also counted. In order to save space these data are not given in full, but their analysis is discussed below.

Analysis of Data

In order to study the effect of plot orientation on the efficiency of shape in controlling soil heterogeneity, plots of various shapes were formed by combining in different ways adjoining ultimate units. The

TABLE 1. *Yield per Unit in Kg. of Seed-cotton for all the 1,024 Ultimate Units*

TABLE 1. *Yield per Unit in Kg. of Seed-cotton for all the 1,024 Ultimate Units*

4-metre lengths	Rows: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Block A																
1	1·23	1·07	1·07	1·09	1·05	1·17	1·06	1·05	1·13	1·13	1·13	1·23	1·19	1·05	0·99	0·92
2	0·90	0·79	0·79	0·98	0·83	1·19	1·11	1·00	1·15	1·30	1·35	1·23	1·20	1·11	1·00	1·10
3	0·97	0·76	0·86	0·86	0·97	1·08	1·15	1·08	1·17	1·19	1·34	1·20	1·28	1·16	1·18	1·23
4	1·10	0·85	0·92	0·98	0·78	1·01	1·07	1·20	1·16	1·33	1·33	1·15	1·32	1·31	1·43	1·02
5	0·99	1·23	1·13	0·90	0·80	1·10	1·16	1·20	1·06	0·88	1·17	1·16	1·27	1·10	1·19	1·09
6	1·43	1·20	0·97	0·92	1·05	1·27	1·21	1·20	1·03	0·74	1·20	1·15	0·82	0·93	0·97	0·88
7	1·51	1·36	1·15	0·79	1·16	1·02	0·84	0·79	0·75	0·81	0·95	1·11	1·05	0·93	1·06	0·64
8	1·26	1·20	1·04	1·00	0·95	1·19	1·14	0·97	0·94	0·80	0·79	1·04	1·01	0·96	1·05	1·33
9	1·15	1·11	0·95	0·91	0·93	1·08	1·02	0·75	0·95	0·79	0·96	1·04	1·02	1·03	0·93	0·74
10	1·13	1·19	1·23	1·12	1·04	1·25	1·45	1·01	1·03	0·98	0·98	1·07	1·14	1·20	1·16	1·23
11	1·01	1·05	1·12	1·10	0·85	1·05	0·95	0·85	0·98	0·91	1·24	0·93	0·85	0·72	0·64	0·77
12	1·14	0·92	0·98	0·89	0·81	1·01	1·12	0·86	1·10	0·83	1·39	1·24	0·78	1·03	1·27	0·68
13	1·20	1·18	1·24	1·05	1·12	1·04	0·97	1·18	1·38	1·30	1·13	0·94	1·22	1·14	1·17	1·34
14	1·44	1·55	1·40	1·34	1·26	1·28	1·29	1·14	1·29	1·19	1·25	0·97	1·05	0·98	1·02	1·15
15	1·66	1·38	1·39	1·29	1·28	1·27	1·19	1·30	1·39	1·23	1·38	1·09	1·17	1·17	1·20	1·11
16	1·35	1·37	1·11	1·16	1·10	1·16	1·09	1·24	1·27	1·31	1·38	1·35	1·37	1·22	1·16	1·23
Block B																
1	1·07	1·11	1·08	1·17	0·98	0·96	0·93	0·97	1·02	0·90	0·93	0·94	1·20	1·07	1·27	1·36
2	1·02	1·14	1·04	1·21	1·17	0·97	0·92	1·20	1·03	1·04	1·28	1·21	1·23	1·28	1·29	1·42
3	1·23	1·22	1·28	1·05	1·04	1·07	1·22	1·16	1·18	1·20	1·19	1·29	1·13	1·25	1·16	1·28
4	1·03	1·09	1·00	1·00	1·04	1·09	1·24	1·26	1·14	1·22	1·33	1·03	1·19	1·10	1·05	0·87
5	1·11	1·06	0·83	0·83	1·09	0·82	1·07	0·98	1·25	1·28	1·13	0·83	0·96	1·10	1·07	1·26
6	1·22	1·13	1·27	1·09	1·14	1·28	1·19	1·07	1·12	0·93	0·78	0·75	0·80	0·86	1·00	1·17
7	1·04	1·16	1·21	1·27	1·21	1·27	1·13	1·08	1·16	0·98	1·02	0·83	0·61	0·70	0·74	0·71
8	1·01	1·28	1·27	1·13	0·95	1·16	0·69	1·12	0·87	0·98	1·03	0·97	0·93	0·89	0·78	0·64
9	1·15	1·17	0·86	0·98	1·02	0·98	0·84	0·68	0·79	0·71	0·84	0·82	0·83	0·79	0·70	0·79
10	1·19	1·11	1·12	1·19	1·14	1·08	1·10	0·91	1·01	0·79	0·79	0·88	1·12	0·94	0·81	0·93
11	1·37	1·13	1·36	1·20	1·00	1·31	1·10	1·00	1·08	0·96	0·84	1·25	1·09	1·30	1·06	1·02
12	1·35	1·14	1·17	1·06	0·85	0·88	1·19	1·20	1·36	1·11	1·13	1·31	1·25	1·32	1·29	1·28
13	1·03	1·05	0·81	1·01	0·92	1·19	0·94	0·98	1·18	1·37	1·03	1·20	1·37	1·30	1·44	1·28
14	1·20	1·21	1·04	1·17	1·23	1·19	1·14	1·20	1·23	1·24	1·22	1·36	1·30	1·27	1·40	1·33
15	1·28	1·02	1·06	1·16	1·27	1·41	1·22	1·48	1·28	1·56	1·24	1·35	1·45	1·28	1·18	0·99
16	1·19	1·26	1·10	1·24	1·28	1·29	1·17	1·37	1·18	1·15	1·35	1·41	1·32	1·25	1·04	1·26

4-metre lengths	Rows: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Block C																
1	1·16	1·31	1·08	1·22	1·08	1·03	0·88	1·06	1·06	0·82	1·07	1·17	0·98	1·03	0·91	0·75
2	0·98	1·24	1·02	1·22	1·14	1·06	1·11	1·02	1·34	0·94	1·23	1·15	1·15	1·06	1·20	0·96
3	1·14	0·94	1·14	1·20	1·43	1·20	1·10	1·11	1·17	1·13	1·32	1·19	1·14	1·12	1·24	1·02
4	1·04	1·23	0·90	1·21	1·35	1·31	1·08	1·04	1·08	1·06	1·05	1·06	0·95	1·22	0·99	0·81
5	1·07	0·77	0·80	0·90	1·06	1·26	1·34	0·84	1·15	1·08	1·18	1·01	0·94	1·09	0·95	0·80
6	0·88	0·83	0·79	1·13	1·20	1·30	1·08	1·16	1·19	1·28	1·20	1·51	1·10	1·20	1·27	0·97
7	1·08	0·79	0·74	0·93	1·07	1·09	1·20	0·98	1·18	1·20	1·11	1·09	1·19	1·05	1·06	1·27
8	1·04	1·03	0·56	0·71	0·63	0·58	0·50	0·73	1·00	0·99	0·86	1·00	0·82	0·73	1·22	1·11
9	0·75	1·02	0·84	0·68	0·36	0·51	0·45	0·48	0·60	0·67	0·82	0·86	0·92	0·74	1·11	1·10
10	0·72	1·03	1·26	0·90	0·89	0·68	0·76	0·50	0·39	0·53	0·47	0·93	1·00	1·02	1·18	1·33
11	0·79	0·74	0·86	0·82	0·95	0·75	1·10	0·73	0·63	0·41	0·42	0·57	0·64	0·89	1·11	1·29
12	0·74	0·67	0·81	0·51	0·66	0·71	0·62	0·66	0·45	0·42	0·47	0·57	0·67	1·19	1·07	0·93
13	0·65	0·59	1·00	0·94	1·04	0·84	0·65	0·75	0·66	0·38	0·57	0·37	0·50	0·69	0·76	0·81
14	0·66	0·62	0·66	0·63	0·82	1·02	0·63	0·59	0·69	0·47	0·40	0·39	0·42	0·58	0·57	0·58
15	0·62	0·66	0·54	0·60	0·75	1·06	0·93	0·90	0·78	0·80	0·68	0·75	0·74	0·58	0·56	0·53
16	0·87	1·01	0·83	0·78	1·04	1·14	0·99	1·07	1·28	1·28	0·81	1·13	1·10	0·66	0·64	0·63
Block D																
1	1·00	1·16	0·86	0·81	0·85	0·95	1·31	0·83	0·81	0·66	0·94	0·99	0·99	1·10	1·13	1·21
2	0·67	0·54	0·64	0·72	0·60	0·91	1·02	0·71	0·66	0·78	0·82	0·94	0·75	0·88	0·93	0·68
3	0·98	1·16	0·74	1·09	0·97	1·14	1·18	0·85	0·77	0·91	1·02	0·82	0·86	0·79	1·07	0·94
4	0·96	1·25	1·06	0·90	0·96	1·11	1·26	1·20	0·81	1·12	0·96	0·99	0·94	0·92	0·91	1·08
5	1·16	1·01	1·19	0·93	1·09	1·00	1·20	1·03	1·07	1·03	1·44	1·21	1·12	1·10	1·11	1·07
6	1·07	1·03	0·90	0·84	1·11	0·95	0·98	1·04	1·08	1·36	1·65	1·03	1·18	1·06	0·97	0·82
7	0·67	0·93	0·93	0·68	0·67	1·01	1·29	1·10	1·06	1·27	0·76	1·11	1·14	1·02	1·13	1·06
8	0·84	0·99	0·92	1·01	1·02	1·03	1·03	0·84	1·01	1·23	0·83	1·04	0·86	1·08	1·00	0·80
9	0·75	1·15	0·69	1·03	0·94	0·70	1·02	1·04	1·02	0·78	0·98	0·88	0·88	1·12	1·12	1·19
10	0·61	0·60	0·64	0·60	0·82	0·76	0·93	0·84	0·69	0·54	0·61	0·73	0·74	0·89	1·05	0·96
11	0·61	0·62	0·50	0·40	0·57	0·69	0·53	0·68	0·64	0·61	0·55	0·59	0·80	0·75	1·06	0·84
12	0·62	0·64	0·60	0·54	0·66	0·68	0·65	0·77	0·69	0·84	0·71	0·90	0·63	0·53	0·88	0·69
13	0·77	0·85	0·75	0·70	1·15	0·62	0·69	0·71	0·68	0·66	0·67	0·77	0·81	0·77	0·69	0·84
14	1·00	1·05	1·00	1·07	1·11	0·98	0·95	0·73	0·61	0·68	0·68	0·79	0·68	0·59	0·72	0·87
15	1·16	1·13	0·84	0·91	0·97	0·90	0·79	0·73	0·73	0·67	0·62	0·90	0·86	0·78	0·69	0·79
16	1·03	1·08	0·90	1·01	0·78	1·05	0·78	1·20	1·06	1·00	1·37	1·01	1·17	1·20	1·21	1·06

number of units in each plot was always 16, each group (A, B, C, or D) providing 16 plots for every shape.

As illustrated in Fig. 2, five different shapes can be formed from the units of every group, as follows:

w/l	*Method of forming the combination plots*
1/64	1 row wide and 16 sections (4-metre lengths) long
1/16	2 rows ,, ,, 8 ,, ,, ,, ,,
1/4	4 ,, ,, ,, 4 ,, ,, ,, ,,
1/1	8 ,, ,, ,, 2 ,, ,, ,, ,,
4/1	16 ,, ,, ,, 1 section ,, ,, ,,

In order to compare in each block the variability of the 16 plots of every shape, the total sum of squares and the residual sum of squares after eliminating blocks of four plots (arranged as in Fig. 2) were determined. The results obtained are given in Table 2 (page 337).

With the shape $w/l = 1/4$ the statistical analysis may be brought a step farther by assuming a Latin-square plot arrangement. In all four blocks, however, the Latin-square design is slightly *less* effective than the randomized-block design, as shown by the following figures:

Shape of blocks $w/l = 1/4$	*Residual mean squares with*	
	Randomized blocks	*Latin squares*
A	1·63	1·97
B	1·61	2·06
C	3·79	4·84
D	1·34	1·51

There is no doubt that in all four orientations plot variability increases consistently as the ratio w/l approaches unity. A few negligible discrepancies may be seen, particularly one in block C, where square plots ($w/l = 1/1$) were found slightly less variable than plots somewhat longer and more narrow in shape ($w/l = 4/1$ or $1/4$). Such divergencies are not statistically significant, that of block C being explained by the particular heterogeneity at the lower part of that block, as illustrated in the contour map (Fig. 1). If longer plots are considered ($w/l = 1/16$ or $1/64$) the advantage of long plots is again considerable.

If all four blocks are considered together (Table 2, blocks A, B, C, and D), for each shape there is a total of 63 degrees of freedom, from which 15 should be allotted to replications and 48 to error. The statistical analysis provides clear evidence that square plots ($w/l = 1/1$) are the most variable of those tested. Plots of a ratio $w/l = 1/4$ or $4/1$, having the same shape but arranged at right angles to each other, have almost identical variability. The above conclusions hold good either for the residual sum of squares or for the total variability.

Number of plants—It is interesting to investigate whether the number of plants per plot, which is presumably not directly affected by soil heterogeneity, had any effect on the variability of each shape. From the analytical data of the number of plants per plot the sums of squares

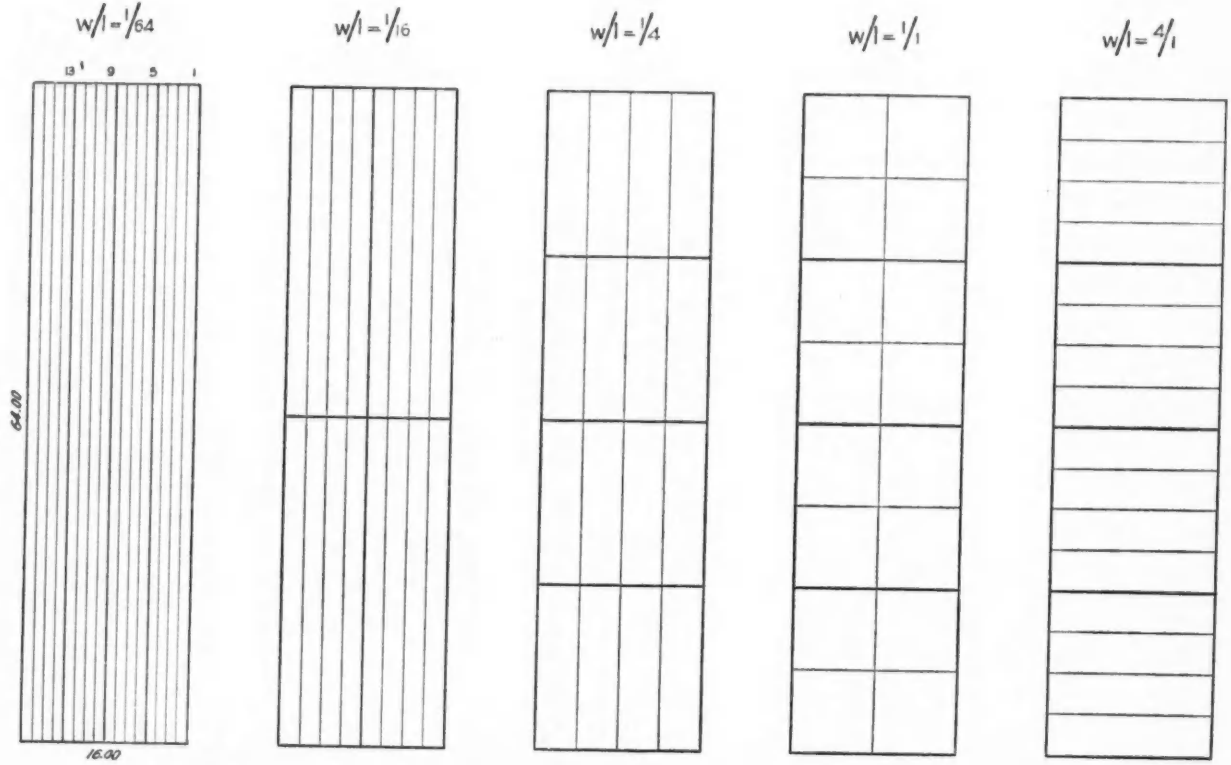

FIG. 2. The five shapes of plot available (thick lines show the way in which blocks were formed).

(total and residual) were worked out for all blocks A, B, C, and D, and for all possible shapes, with the results given in Table 3.

The sums of squares are on the whole very small, showing that the number of plants per plot was very uniform. On the other hand, the

TABLE 2. *Variability in Yield for Plots of Various Shapes and Orientation*

Shape w/l	*Sums of squares*		
	Total D.F. = 15	*Between replications D.F. = 3*	*Residual D.F. = 12*
Block A. (Mean yield per plot = 17·51 kg.)			
1/64	13·35	1·78	11·57
1/16	14·90	4·36	10·54
1/4	47·36	27·81	19·55
1/1	46·16	27·81	18·35
4/1	37·48	27·81	9·67
Block B. (Mean yield per plot = 17·65 kg.)			
1/64	2·29	0·78	1·51
1/16	8·21	4·81	3·40
1/4	43·33	24·04	19·29
1/1	58·44	24·04	34·40
4/1	44·39	24·04	20·35
Block C. (Mean yield per plot = 14·52 kg.)			
1/64	7·36	1·98	5·38
1/16	109·52	93·49	16·03
1/4	141·15	95·62	45·53
1/1	123·34	95·62	27·72
4/1	129·13	95·62	33·51
Block D. (Mean yield per plot = 14·41 kg.)			
1/64	8·37	2·50	5·87
1/16	37·26	27·99	9·27
1/4	55·59	39·53	16·06
1/1	70·95	39·53	31·42
4/1	79·37	39·53	39·84
Blocks A, B, C, and D. (Mean yield = 16·02 kg.)			
	D.F. = 63	D.F. = 15	D.F. = 48
1/64	186·94	162·61	24·33
1/16	325·47	286·23	39·24
1/4	442·99	342·56	100·43
1/1	454·47	342·56	111·91
4/1	445·94	342·56	103·38

$n_1 = 12$, $n_2 = 12$ and $P = 5\%$, $z_0 = 0{\cdot}4941$

For:

$n_1 = 48$, $n_2 = 48$ and $P = 5\%$, $z_0 = 0{\cdot}2391$

FIG. 2. The five shapes of plot available (thick lines show the way in which blocks were formed).

variance decreases consistently with plots including sections of as many rows as possible (with the exception of shape $w/l = 1/1$). The figures indicate that, despite great care having been taken to secure uniform depth, rate of seeding, &c., at sowing-time, the variance between individual rows is higher than that between units of same area but consisting of sections of several rows.

Covariance between yield and plant number.—In view of the above evidence an analysis of covariance between yield and plant number was carried out, in order to determine whether variability in yield would be altered when proper allowance is made for variation in plant number. The residual sums of products (after deducting the amount due to covariance between replications) obtained for each shape and every block are shown in Table 4, from which it can easily be seen that covariance between yield and plant number is very erratic.

TABLE 3. *Plant Number. Blocks A, B, C, and D.* (*Mean number of plants in plot* = 278·8)

Shape w/l	*Sums of squares*		
	Total D.F. = 63	*Between replications, D.F.* = 15	*Residual D.F.* = 48
1/64	16·37	9·33	7·04
1/16	15·74	9·99	5·75
1/4	13·68	8·88	4·80
1/1	13·95	8·88	5·07
4/1	11·62	8·88	2·74

TABLE 4. *Residual Covariance between Yield and Plant Number*

Shape w/l	*Blocks*				
	A	*B*	*C*	*D*	*A*+*B*+*C*+*D*
1/64	61·43	11·72	71·68	29·52	174·33
1/16	5·38	8·82	− 1·68	− 8·62	3·90
1/4	−48·00	91·61	−54·37	1·56	− 9·20
1/1	10·41	142·56	46·38	−50·71	148·64
4/1	−10·95	48·75	93·06	−48·76	82·10

If all four blocks be taken into account together, the covariance for shape $w/l = 1/64$ is certainly significant, whereas for the other four shapes it is quite negligible. Table 5 shows what part of the residual sum of squares (Table 2, blocks A, B, C, and D) is due to regression of yield on plant number and what to error.

TABLE 5. *Analysis of Residual Variances*

Shape w/l	*Residual sum of squares*			*Mean square due to*	
	Total $S(y-\bar{y})^2$ *D.F.* = 48	*Due to regression* $b^2S(x-\bar{x})^2$ *D.F.* = 1	*Due to deviations* $S(y-Y)^2$ *D.F.* = 47	*Regression*	*Deviations*
1/64	24·33	4·30	20·03	4·30	0·43
1/16	39·59	0·00	39·59	0·00	0·84
1/4	100·43	0·02	100·41	0·02	2·14
1/1	168·58	5·57	163·01	5·57	3·47
4/1	103·38	2·46	100·92	2·46	2·15

The variability of $w/l = 1/64$ is obviously increased by the fact that the number of plants per plot is not as uniform as in the other shapes.

If this factor could be kept under control, the S.D. (per cent. of the mean) for $w/l = 1/64$ would be $\frac{100}{16{\cdot}02}\sqrt{\frac{20{\cdot}03}{47}} = 4{\cdot}03$, instead of 4·44.

Irrigation.—Irrigation was effected by means of small ditches running along the rows. The amount of water given to these ditches was necessarily variable, since the only way of measuring it consisted in allowing every ditch to overflow. If it had been possible to determine in a more accurate way the quantity of water given to each row, or preferably to each section of a row, its variation could have been studied in connexion with the yield obtained. This might have shown that, as in the case of the number of plants, irrigation also may increase the variability of long single-row plots. However, in spite of possible inequalities of irrigation, as well as of other sources of irregularity (unequal distances between the rows, former paths, &c.), which have nothing to do with soil heterogeneity, and which in a proper experiment should for all practical purposes be kept under control, long plots are undoubtedly very considerably less variable than square plots.

Loesell's Data

Of the data of blank experiments published since 1931, Loesell's [8] seem quite appropriate for studying the variability of different shapes. Accordingly, his first 80 rows and 16 sections (1,280 units) were used and plots of various shapes were formed by combining 16 ultimate units in precisely the same way as in the case of Sindos. However, the five values w/l available are now slightly different, amounting to:

1/68·5	=	1 row,	16 sections
1/17·1	=	4 rows,	4 ,,
1/1·1	=	8 ,,	2 ,,
3·7/1	=	16 ,,	1 section

The variability of every shape (total or residual, after allowing for variation between replications taken as in the case of Sindos), is given in Table 6, which is similar to Table 2 above. The results obtained show the closest agreement with those reached at Sindos, leaving no doubt that long narrow plots control soil heterogeneity better than square plots.

Summary and Conclusions

1. Almost all workers who have studied the importance of the shape of plot since 1931 have concluded that long and narrow plots are much more effective than squares in controlling soil heterogeneity. (Two contradictory cases reviewed in this paper are obviously due to factors other than soil heterogeneity.)

2. To find out whether the above conclusion holds good, no matter what the plot orientation adopted, a suitable experiment was devised in which 5 different shapes were compared in 4 different orientations, varying by 30° from each other.

3. The results obtained are definitely conclusive. Long rows may vary not only on account of soil heterogeneity but also under the influence of other factors (irregular planting or watering along the rows,

TABLE 6. *Analysis of Loesell's Data*

Shape w/l	*Sum of squares*		
	Total D.F. = 15	*Between replications D.F. = 3*	*Residual D.F. = 12*
Rows 1 to 16. (Mean yield = 7·51 kg.)			
1/68, 5	1·90	0·50	1·40
1/17, 1	3·10	1·85	1·25
1/41, 3	3·55	1·40	2·15
1/ 1, 1	7·20	1·40	5·80
3, 711	6·96	1·40	5·56
Rows 17 to 32. (Mean yield = 7·66 kg.)			
1/68, 5	1·35	0·74	0·61
1/17, 1	1·44	0·78	0·66
1/4, 3	2·29	1·11	1·18
1/1, 1	4·21	1·11	3·10
3, 7/1	4·35	1·11	3·24
Rows 33 to 48. (Mean yield = 7·70 kg.)			
1/68, 5	2·11	0·75	1·36
1/17, 1	2·14	0·66	1·48
1/4, 3	8·04	6·55	1·49
1/1, 1	11·03	6·55	4·48
3, 7/1	12·45	6·55	5·90
Rows 49 to 64. (Mean yield = 6·65 kg.)			
1/68, 5	4·41	2·91	1·50
1/17, 1	3·91	2·00	1·91
1/4, 3	5·73	2·21	3·52
1/1, 1	8·14	2·21	5·93
3, 7/1	7·21	2·21	5·00
Rows 65 to 80. (Mean yield = 6·92 kg.)			
1/68, 5	1·95	1·05	0·90
1/17, 1	7·18	5·20	1·98
1/4, 3	9·43	5·67	3·76
1/1, 1	10·09	5·67	4·42
3, 7/1	7·60	5·67	1·93
Rows 1 to 80. (Mean yield = 7·29 kg.)			
	D.F. = 79	D.F. = 19	D.F. = 60
1/68, 5	26·22	20·45	5·77
1/17, 1	32·29	25·01	7·28
1/4, 3	43·56	31·45	12·11
1/1, 1	55·19	31·45	23·74
3, 7/1	53·08	31·45	21·63

$n_1 = 12$, $n_2 = 12$ and $P = 5\%$, $z_0 = 0{\cdot}4941$

For:

$n_1 = 60$, $n_2 = 60$ and $P = 5\%$, $z_0 = 0{\cdot}2113$

unequal distances between them, &c.), the effect of which is diminished by increasing the number of rows included in the same plot. Despite this fact it was found that, in all orientations tested, plot variation depended closely on the shape of plot, decreasing considerably by the

use of plots as long and narrow as possible. The S.D. (per cent. of the mean) for each shape, when all orientations are taken into account together, was as follows:

w/l	*S.D.*
1/64	4·4
1/16	5·6
1/4	9·0
1/1	9·5
4/1	9·2

4. Only in the case of the longest shape ($w/l = 1/64$) was there found a significant covariance between the number of plants per plot and the respective yields obtained. If the number of plants were to be kept uniform for all rows (or allowance made for any variation by the method of the analysis of covariance), the advantage of plots consisting of only one long row would be slightly accentuated.

5. Additional evidence is provided by the analysis of Loesell's data secured at Michigan. The results show close agreement with those of Sindos, the S.D. (per cent. of the mean) for various shapes being:

w/l	*S.D.*
1/68·5	4·3
1/17·1	4·8
1/4·3	6·2
1/1·1	8·6
3·7/1	8·2

6. It is thus obvious that for all practical purposes long narrow plots control soil heterogeneity considerably better than square ones. This confirms arguments brought forward elsewhere [1].

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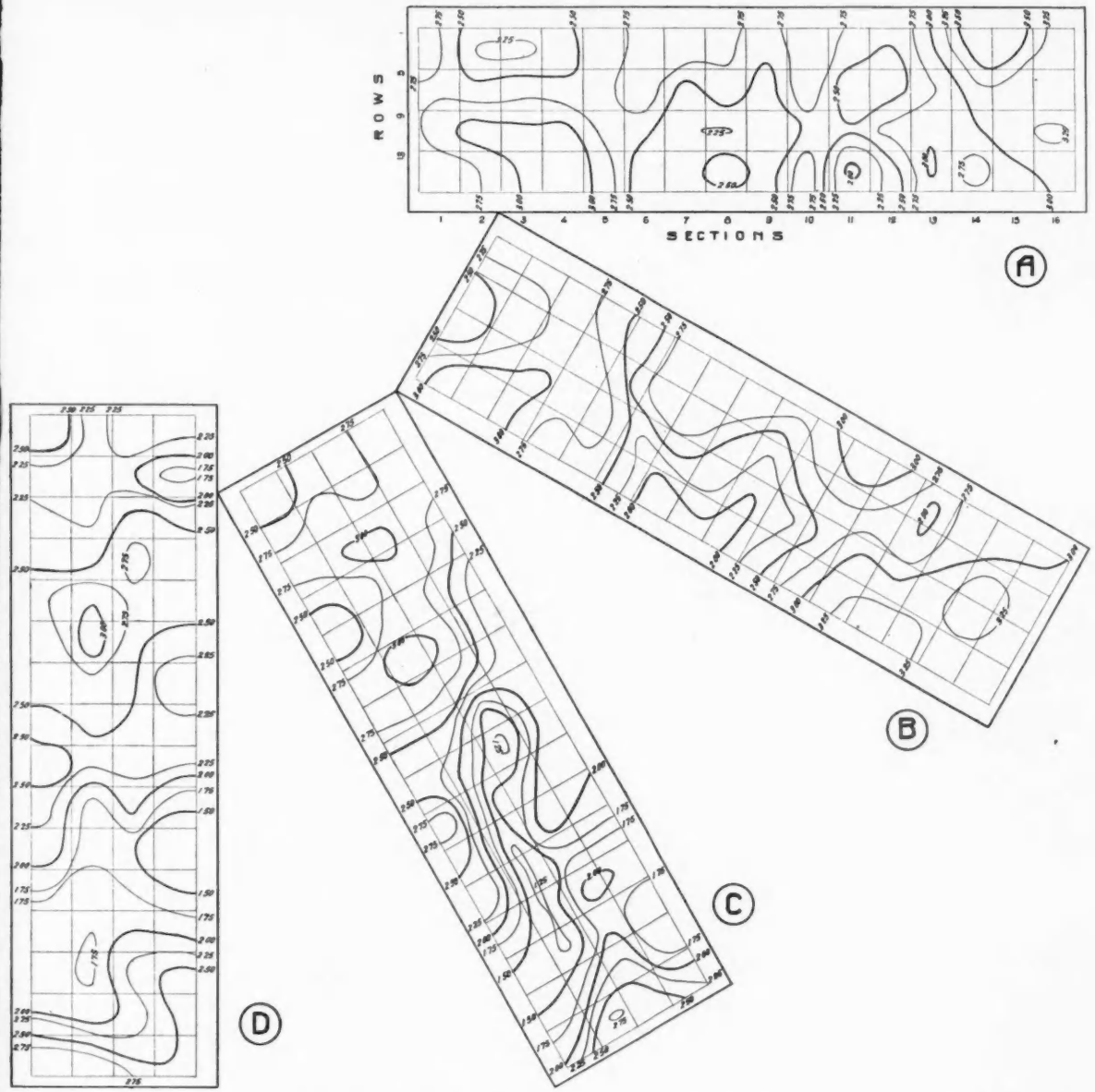

FIG. 1. Fertility contour map of Sindos data. The contours denote kilograms of seed-cotton per stremma (=1000 sq. m.)

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THE RESIDUAL EFFECTS OF ORGANIC FERTILIZERS: A PRELIMINARY REPORT ON THE ROTHAMSTED FOUR-COURSE ROTATION EXPERIMENT

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IN 1930 a rotation experiment was commenced in Great Hoosfield, Rothamsted. Its object is primarily to investigate the residual effects of organic and inorganic fertilizers on four crops grown in a Norfolk rotation, namely, a four-year cycle of barley, rye-grass, wheat, and potatoes. Swedes were grown instead of potatoes in 1930 and 1931, and a mixture of clover and rye-grass was grown in place of rye-grass from 1930 to 1934.

The five treatments compared are:

Organic fertilizers
1. Farmyard manure.
2. Adco compost.
3. Straw and artificials.

Inorganic fertilizers
4. Superphosphate.
5. Rock phosphate (Gafsa).

Table 1 shows the average quantities of each fertilizer given. In Treatment 3 as much straw is ploughed in as went to the making of the Adco compost: owing to varying losses of organic matter on rotting this amount varies from year to year. The total amounts of N, P_2O_5, and K_2O are held constant for Treatments 1, 2, and 3 by the addition of the requisite amounts of artificial fertilizers. The organic fertilizers and their accompanying artificial fertilizers in Treatments 1, 2, and 3 are applied once in five years only. The phosphatic fertilizers in Treatments 4 and 5 are also applied once every five years, but the sulphate of ammonia and muriate of potash in these two treatments are applied annually. There is thus a five-year treatment cycle as well as a four-year crop cycle, the treatments being in five 'phases'. Information is

TABLE 1. *Fertilizer Treatments: Average for 1931–4.*

	Organic fertilizers (cwt. per acre)				*Additional inorganic fertilizers (cwt. per acre)*		
Treatment	*Organic matter*	*N*	P_2O_5	K_2O	*N as S. of A.*	P_2O_5 *as Super.*	K_2O *as Mur. of Pot.*
1	50 (as f.y.m.)	1·540	0·742	2·266	0·260	0·476*	0·922*
2	50 (as Adco)	1·402	1·148	0·844	0·398	0·124*	2·156
3	128·47 (as straw)	0·702	0·275	2·177	1·098	0·926	0·823
4	None	None	None	None	0·36	1·2	0·6
5	None	None	None	None	0·36	1·2†	0·6

* The totals for P_2O_5 in Treatments 1 and 2 are over 12 cwt., since there was an excess in the years 1934 and 1938. Similarly there was an excess in K_2O in Treatment 1 in 1938.

† As mineral phosphate.

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obtained on the effect of treatment not only in the year of application, but in the first, second, third, and fourth years after application as well.

Full details of the composition and times of application of the fertilizers will be found in the Rothamsted Annual Reports from 1930 onwards.

The experiment is laid down on four areas, termed 'series'. Each series grows one of the crops of the rotation, so that each crop is represented every year. Each series is divided into 5 blocks, each containing 5 plots of approximately 1/40th of an acre.

Each block contains all 5 treatments, but in different phases, these being so chosen that each phase is also represented in each block. Each plot receives always the same treatment.

The data each year consist, therefore, of the yields of 25 plots from each of 4 crops, and these 25 plots include each of 5 treatments in each of 5 phases. It is intended that the experiments shall run for at least 20 years, excluding the 4 preliminary years, by which time each plot will have grown every crop at every phase. Including the preliminary years, 9 years' results are now available.

Data Used

The years from 1930 to 1933 must be regarded as preliminary, since only from 1934 onwards have all the plots been treated at least once. In order to retain as many of the data as possible, however, all years from 1931 onwards have been included in the present analysis of the two cereal crops. For the organic treatments, plots which had not yet received treatment were included as if they had already been treated according to their proper phase. Little disturbance is likely to have been introduced by this device, as the residual effects in the last three phases of the cycle are, as will be seen later, small.

Had the annual application of the nitrogenous and potassic fertilizers in the inorganic treatments commenced in 1931, eight years' results could have been similarly made up for these treatments, since all plots would have received their annual dressings. In 1930 and 1931, however, owing to a misunderstanding, plots which had not yet received their phosphatic treatment received no fertilizer at all. In order to obtain comparable results, therefore, the yields of Phases III, IV, and V were taken as equal to those of Phase II in 1931. The disturbance following this device is again likely to be slight, since the only statistical analyses involving these figures have been carried out on the totals of all five phases and not on the individual phases.

Potatoes were grown only from 1932 onwards, giving seven years' results, and rye-grass from 1935 onwards, giving four years' results.

Experimental Results

The average effects of each fertilizer over all phases for each crop are shown in Table 2, which gives the mean yield per acre taken over all five phases for all years. Residual effects may be studied in Graphs 1–4, which show the mean yields for each phase of each treatment, taken over all years.

Average effects.—Table 2 shows that though the average effects of the

organic fertilizers for the two cereal crops considered separately are scarcely significantly different, straw + artificials has done significantly better on the mean of the two crops. In the case of rye-grass also, straw+artificials was better than either farmyard manure or Adco, and

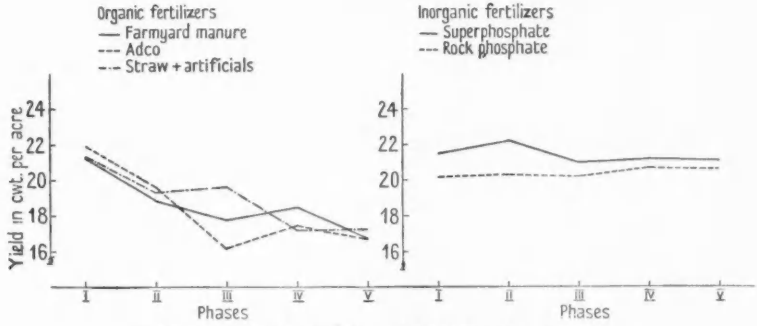
TABLE 2. *Mean Yields per Acre*

Treatment	*Wheat* *Mean of years 1931–8*		*Potatoes* *Mean of years 1932–8*		*Barley* *Mean of years 1931–8*		*Rye-grass* *Mean of years 1935–8*	
	Mean	*S.E.*	*Mean*	*S.E.*	*Mean*	*S.E.*	*Mean*	*S.E.*
	Cwt. per acre		Tons per acre		Cwt. per acre		Cwt. per acre	
Farmyard manure	19·0	0·31	3·64	0·11	20·4	0·35	19·7	1·13
Adco	18·8		3·01		20·2		20·3	
Straw+artificials	19·7		3·61		21·3		25·5	
Superphosphate	21·4	0·44	4·30	0·09	26·2	0·57	32·3	0·66
Rock phosphate	20·4		3·31		23·2		30·2	

for potatoes (for which all yields were very poor) farmyard manure and straw+artificials were both better than Adco. In all crops the superphosphate gave better results than the rock phosphate, the difference being significant in all crops except wheat.

The comparison of organic fertilizers with inorganic is hardly a fair one, since the nitrogenous and potassic supplements for the inorganic fertilizers were given annually, and, as might be expected, produced better average yields. The only exception was in the case of rock phosphate applied to potatoes, which did not give as good results as the farmyard manure or straw+artificials.

Standard errors of means for the organic treatments were computed from the 'years × treatments' term in an analysis of variance of the

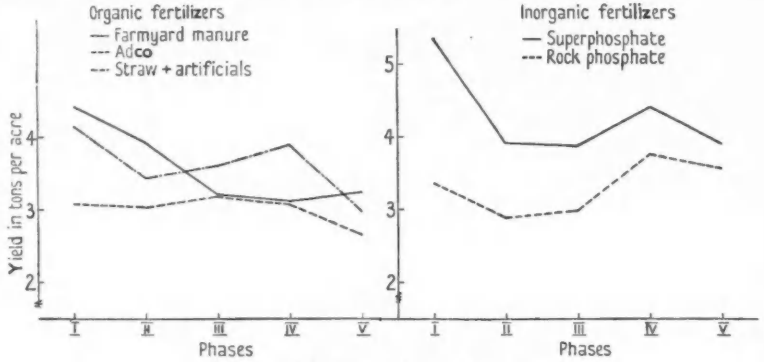


GRAPH 1. Wheat. Mean yields of grain, 1931–8.

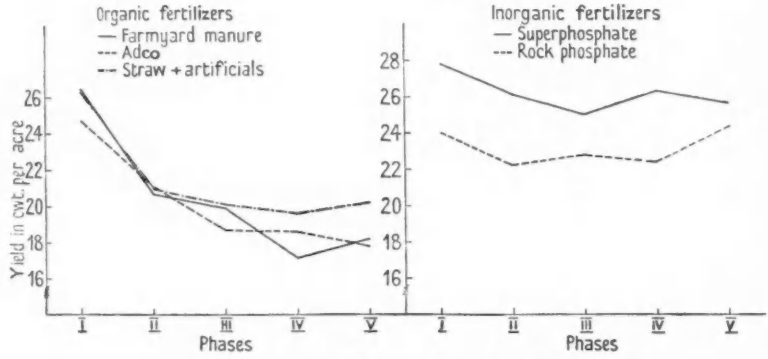
yields per plot. Those for the inorganic treatments were computed from a similar analysis involving these treatments only. A typical analysis (that for barley for the organic treatments) is shown in Table 3 and is discussed in more detail in the following section.

Residual effects.—A study of Graphs 1–4 shows the differences between

the immediate and residual responses to the various treatments. Wheat, barley, and rye-grass showed a marked initial response to all three organic fertilizers, with a subsequent fall in yield. The immediate response of rye-grass to straw+artificials was particularly marked. Potatoes showed little apparent initial response to Adco, but there were in fact no significant differences between the three curves other than the



GRAPH 2. Potatoes. Mean yields, 1932–8.



GRAPH 3. Barley. Mean yields of grain, 1931–8.

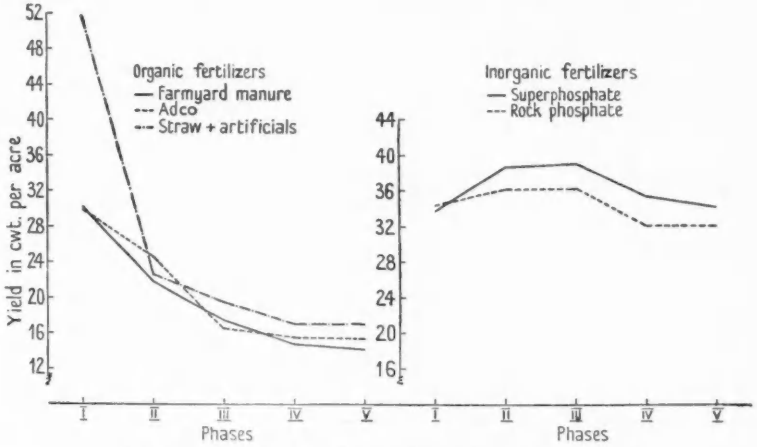
lower average yield with Adco already referred to. The standard errors for this crop were high.

The residual responses in the year after application of the organic fertilizers are also clearly shown, being of the order of one-third the initial responses. There is also some indication of further small residual effects in the subsequent years.

The significance of apparent differences in the response curves for the different organic fertilizers may be assessed from an analysis of variance of the type shown in Table 3.

Barley has been chosen for discussion because an apparent divergence in the graphs is shown by the analysis not to be significant.

In studying the five phases of treatment, the most interesting procedure is to split up sums of squares into the four parts corresponding to the four regression coefficients, of which the linear (measuring the rate of



GRAPH 4. Rye-grass. Mean yields of dry matter, 1935–8.

the fall in yield after the initial response) and the quadratic (measuring the slackening of the rate of fall) are the most important. The pure-phases term in the analysis is derived from the totals of all three treatments, and so measures the mean regression coefficients for the three treatments

TABLE 3. *Barley Grain. Analysis of Variance of Yields per Plot (in lb). Treatments 1–3*

Source of variance	*Degrees of freedom*	*Sum of squares*	*Mean square*
Years	7	18603·58	2657·65
Phases			
Linear	1	5064·61	5064·61
Quadratic	1	1532·16	1532·16
Cubic	1	59·00	59·00
Quartic	1	59·59	59·59
Treatments	2	208·44	104·22
Years × phases			
Linear	7	2605·49	372·21
Quadratic	7	295·82	42·26
Cubic	7	723·44	103·35
Quartic	7	1282·26	183·18
Years × treatments	14	508·38	36·31
Phases × treatments			
Linear	2	110·06	55·03
Quadratic	2	58·84	29·42
Cubic	2	3·45	1·72
Quartic	2	117·08	58·54
Years × phases × treatments	56	3629·89	64·81
Total	119	34863·13	

Conversion factor from (lb. per plot)^2 to (cwt. per acre)^2 = $(0{\cdot}366441)^2 = 0{\cdot}134279$.

taken together. Comparison should be made with corresponding portions of the 'years × phases' term, and this comparison shows that the linear and quadratic terms are significant at the 1 per cent. level. This observation merely confirms what is obvious from inspection of the graphs, in which all three curves show a drop in yield after Phase I, but the curve does not maintain the same rate of fall and flattens out towards the later phases. Differences between the three curves are tested by comparing the four parts of the 'phases × treatments' term with 'years × phases × treatments'. The latter term could have been shown split into four parts, but as these were similar they have been pooled. The graph seems to indicate that the plots receiving straw + artificials did not show as great a fall in yield as the plots receiving the other two treatments, but the analysis of variance shows that this apparent difference is not significant, each of the parts of the 'phases × treatments' term being less than the 'years × phases × treatments' term.

The 'years × phases' term, which is also compared with 'years × phases × treatments', shows differences between regression coefficients in the different years. In other words it shows up differences between the eight curves for the mean of the three organic fertilizers which might have been plotted, one for each year. As might have been expected, the response curves are different in different years.

Similar analyses were carried out for the other crops. The results for wheat grain were the same as those for barley grain. Rye-grass, however, showed significant differences between regression coefficients for the different organic treatments. These differences are due to the very high initial response to straw + artificials, already commented on, with the subsequent heavy fall in yield. The curve for farmyard manure is similar to that for Adco.

The yields for the inorganic treatments, of course, would not be expected to show such a marked falling off in yield. Potatoes and barley, however, do show an immediate response to superphosphate, the yield in the year of application being higher than the mean of the other four years. The effect is significant in the case of potatoes, but barely so in the case of barley.

Cumulative effects on plots.—Comparison of the trend of organic with inorganic fertilizers is of interest. Table 4 shows the differences between the mean yields of all plots receiving organic and all plots receiving inorganic fertilizers. If one set of plots were gaining on the other, a steady change in each set of figures would be expected. Any such change can be measured by a linear regression coefficient, one of which was computed for each crop. Only in the case of potatoes was the regression significant, and then barely so. The organic plots in this case were catching up on the inorganic. In general, however, there is little evidence that a steady change in relative fertility is taking place, or that varying seasons favour the two types of fertilizer differently.

Summary

1. This report discusses eight years' results from a rotation experiment designed to determine the residual effects of organic fertilizers

which were applied once every five years on barley, rye-grass, wheat, and potatoes.

2. All four crops showed clear evidence of residual effects in the first year after application, and there was also evidence of smaller residual

TABLE 4. *Differences between Mean Yields of all Plots receiving Organic Fertilizers and all Plots receiving Inorganic Fertilizers* (*Organic minus Inorganic*)

	Wheat	*Potatoes*	*Barley*	*Rye-grass*
Year	Cwt. per acre	Tons per acre	Cwt. per acre	Cwt. per acre
1931	−4·9	..	−4·0	..
1932	−2·6	−1·0	−4·2	..
1933	−1·4	−0·5	−3·5	..
1934	+0·3	−0·6	+0·4	..
1935	+0·1	−0·9	−3·8	−11·0
1936	−1·9	+0·3	−3·5	−10·6
1937	−1·9	−0·5	−7·1	−14·5
1938	−1·5	+0·4	−6·5	− 1·8

effects in later years. The yields of potatoes have unfortunately been very poor.

3. There were no differences between the organic fertilizers applied to barley and wheat, but straw+artificials was better than farmyard manure or Adco for both cereals and rye-grass, whilst Adco gave a lower yield for potatoes than did the other two fertilizers.

4. Two inorganic fertilizers (superphosphate and rock phosphate) were applied every five years to other plots, to which nitrogenous and potassic supplements were applied annually. Superphosphate was better than rock phosphate for every crop.

5. There was no evidence that the plots receiving inorganic fertilizers were becoming steadily better or worse than those receiving organic except in the case of potatoes, where the organic-fertilizer plots began by giving a lower yield than the inorganic, but were gradually catching up.

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HIGH PRODUCTION AND ITS RELATION TO DISEASE IN DAIRY CATTLE

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THIS brief paper, on a subject which has at times caused misplaced criticism of individual and national efforts to improve the general producing qualities of dairy cattle, is mainly concerned with the oft-quoted statement that 'the high-producing cow is more susceptible to disease than the low-producing cow'. This impression, which appears to be fairly prevalent not only among dairy farmers but also among veterinary workers, seems to have arisen more from general impressions than from analyses of actual data. On the surface there are many reasons why such a statement would appear to be relatively true, but after examination it seems to need a great deal of qualification.

In the first place, it would be necessary to distinguish between cows fed on unnaturally high planes of nutrition in order to secure high yields, and cows returning high yields under normal herd conditions. To refuse to recognize this distinction would be to deny the effect of forced feeding or 'steaming up', as against the natural and selective utilization by a cow of the available food-supply. Secondly, what is the definition of a high-producing cow? Is she a cow which, although not a high producer, would have been, it is argued, a high producer had she not suffered from disease? Is she a cow which starts off as a high producer and then falls away rapidly in her mature years? or is she a cow which is a high producer over a series of years and then becomes more prone to disease-troubles than her low-producing mate?

The first definition must be ruled out of consideration because such a cow would be indistinguishable from a genetically low producer; on the other hand, each of the two succeeding definitions can be dealt with on the basis of actual data, and they will be discussed in detail later in this paper.

Before proceeding to discuss the data available it would be well to emphasize that from the observational point of view the impression that a high yielder is more apt to break down through disease, &c., than a low producer might quite conceivably arise from the fact that low-producing animals which break down with disease are rapidly culled and are readily dispensed with in any case. The breakdown of the high-producing animal is, however, a serious loss, and naturally forces itself on the farmer's attention.

Theoretically, this whole problem could quite well be solved if the disease-history of low-producing cows were made available in the same way as the history of high-producing cows now automatically becomes available.

As far as possible then, this paper concerns itself purely with the question whether high-producing cows under natural herd conditions suffer, as a consequence of that high production, a greater incidence of

disease. For obvious reasons it is essential to eliminate the separate influence of herd-management factors, and as far as possible this has been done.

Data.—In approaching the whole subject it was felt that a detailed basis of analysis should be used in preference to analysing extensive data in which contributory factors are difficult to control. By using large masses of data the issue is, to a certain extent, confused by summarizing together herds under greatly varying management, whereas management and feeding factors should be held constant and the 'within-herd' effect obtained. In other words—do high-producing cows *within* a herd tend to break down more rapidly than low producers? If the argument is true in general form, then it should also be true in this particular form. This appears to be a much more satisfactory test than one which relies upon losses by general wastage, in which the annual rate of culling is itself a factor influenced by several considerations.

Mastitis.—In 1937 an attempt was made to obtain detailed information on the statement that high-producing cows were more seriously affected by mastitis than low-producing cows. Seeing that payment for milk and cream supplied to factories in New Zealand is made on a butter-fat basis, the statement was investigated from that point of view, i.e. a high-producing cow was taken to mean a high butter-fat-producing cow.

In order to exclude the influence of varying conditions of herd management, the analysis was made in two herds under the same management that had been under Group Herd Test for at least ten years. Carefully recorded observations of udder trouble made in the milking sheds were available for all cows, and during the last two years these herds have been under a periodic leucocyte examination[1] for mastitis control. No animal of less than 5 years of age was included in the analysis, so that in most cases the production average consisted of at least three normal lactations. All available *normal* lactations were included in assessing the productive ability of the individual cows, and the averages quoted are *lifetime* averages. [The lactation in which the cow broke down with mastitis was of course excluded.]

The results of this analysis were as follows:

TABLE 1. *Influence of Udder Trouble on Butter-fat Production*

96 cows which showed no signs of mastitis or which had passed the age of 8 years before having any udder trouble	Averaged *383 lb. of fat.*
24 cows which were recorded as showing slight signs of udder trouble, but which had not as yet broken down	Averaged *385 lb. of fat.*
40 cows which definitely contracted serious udder trouble	Averaged *372 lb. of fat.*

All immature records (2-year and 3-year) were converted to a maturity-equivalent basis.

[1] The leucocyte method of diagnosing mastitis was applied to the control of this disease in New Zealand by Dr. C. S. M. Hopkirk, of the Wallaceville Laboratory of the Department of Agriculture. The method consists in the grouping of cows according to the degree of mastitis or its absence, as indicated by the concentration of leucocytes in a smeared standard loop of gravity cream taken after a composite sample of fore-milk has stood for two hours.

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The difference of 11 lb. of fat between the first and last group is probably not significant, and might be due to the earlier effect of the onset of udder trouble. There does not appear to be any justification, however, for the statement that, within a herd, it is necessarily the high butter-fat producers which are more susceptible to udder trouble.

As it is very difficult to say just at what stage the onset of mastitis affects the total production of a cow, a different method of analysis was used in seven herds which had been tested under the Mastitis Control Scheme of the Department of Agriculture. Five of these herds were practically all Jerseys and two were Shorthorn herds, so that the breed factor does not upset the analysis. Taking only those cows which were

TABLE 2. *Analysis of Butter-fat Tests (per cent. of Fat in the Milk) for Cows affected by Mastitis*

(*7 herds tested under the Department of Agriculture Mastitis Control Scheme*)

Herds	*No. of cows testing above average for herd*	*Equal*	*No. of cows testing below average for herd*
1 & 2*	28	..	32
4	5	1	13
5	10	..	7
7	13	2	14
8	5	1	9
9	6	4	14
Totals	67	8	89

* Combined because of continual interchange of cows.

classified as mastitis cows, the average butter-fat test (i.e. the percentage of fat in the milk) was used to classify cows as either above or below the average butter-fat test for the herd and consequently as high or low producers. This is a rough but reasonable classification, because within a herd or breed it will be found that approximately 60 per cent. of the high butter-fat-producing animals have a butter-fat test equal to or in excess of that of the herd or breed average. This statement has been checked by an analysis of approximately 9,000 pedigree records of cows under group-test in New Zealand.

The percentage of fat in the milk for separate lactations varies very little in an individual cow, and the occurrence of mastitis appears to have little effect on such percentage. This statement was also checked by analysing the butter-fat tests of thirty-four cows tested since 2 years old, and comparing results in the normal years with those in the year in which mastitis was contracted. There was little marked change, and the average for all normal lactations was 4·04 per cent., as against the average test of 4·00 per cent. for the season in which mastitis was contracted. This being so, it appears justifiable to analyse the results of butter-fat tests for all available lactations for those cows which contracted mastitis in the herds in question, and to compare them with the average result for the whole herd. By doing this we automatically exclude from the analysis any possible effect of mastitis on total production of butter-fat or milk. Table 2 shows the results and indicates that there is very little cause for

classifying the high-testing cow as more susceptible than the low-testing cow. It should again be emphasized, of course, that this applies to butter-fat and does not cover the position so far as milk is concerned; in addition the classification of a cow as a high producer by butter-fat test alone must be accepted with some reserve, and in the present case is intended only as an indirect and rather negative attack on the general problem.

Sterility.—Unfortunately it is very difficult to secure detailed information concerning sterility, and I must plead guilty to using the large mass of data which in my introductory remarks was criticized. An analysis of the spread of calving dates for the whole of the New Zealand Co-operative Herd Testing Association (covering approximately 105,000 cows) was made for the 1937–8 season. This analysis showed the total number of cows calving normally in each month and the number of cows which were empty or aborted. After a detailed examination of the spread of calving dates for each district, and carefully checking the position for late and early calving districts, a classification or fertility index was decided upon by taking the percentage of cows calving normally between June 1 and October 31. (Five groups definitely concerned with town supply, and therefore voluntarily extending their calving period, were eliminated from the analysis.)

It would appear reasonable to accept the percentage of cows calving between June 1 and October 31 as a *maximum* index of fertility or, in other words, it would be generally agreed that cows calving outside these dates are having sterility trouble of some kind.[1] The fertility index for each group was then compared with the average butter-fat production per cow for that group and the results are quoted in Table 3.

TABLE 3. *Analysis of Fertility and Production, According to Groups, in N.Z. Co-op. Herd-testing Association, Season 1937–8*

(*Fertility measured by Percentage of Cows Calving between June 1 and October 31.*)

Production range of group (Fat-lb.)	*No. of groups*	*No. of cows*	*Fertility figure Per cent.*
210–19	1	712	85·0
220–9	2	2,725	85·5
230–9	9	11,452	84·3
240–9	9	10,699	84·7
250–9	16	27,174	86·5
260–9	14	20,501	84·4
270–9	12	16,746	85·3
280–9	5	5,176	86·5
290–9	2	3,022	87·6
300–9	2	1,756	83·1

N.B. The above table omits five groups definitely influenced by town supply.

[1] Under New Zealand dairying conditions, with all-the-year-round grassland grazing practically universal, dairy farmers endeavour to calve as many cows as possible in the spring months of July, August, and September, so as to gain a good seasonal lactation from their cows. For this reason it is generally accepted in New Zealand (except for districts concerned with town supply of milk) that cows calving outside the months June to October are in most cases reflecting poor fertility.

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As will be seen, there is little or no justification for assuming a significant correlation of high production with an increased incidence of sterility. The qualification is fully accepted, however, that this analysis should be carried out on a very much more detailed basis before the results can be accepted as definitely conclusive. It is, however, interesting to note that of the four groups having the highest production per cow, two were very good in their fertility index and two relatively poor. The two poor groups were situated on quite a different class of country to the two good groups, and this again illustrates the point that it is probably the herd and feed-conditions under which high production is achieved more than high production itself which influences the incidence of disease. In any case, the corollary is obvious that high production *can* be achieved with a relatively low disease incidence.

General wastage.—In order to test the *within-herd* effect of wastage, an analysis was made of the complete culling for two herds of approximately 120 cows each which had been tested since 1926 and for which complete breeding information for every animal in the herd since that date was available. Lifetime production-records were compiled for all

TABLE 4. *Analysis of Complete Records of all Cows that entered Herd at 2 Years Old and have completed their Herd Life*

Average of 2- & 3-year production	*No. of cows*	*Average lifetime production*	*No. of normal lacts. in lifetime production*	*Aver. no. of seasons in herd*
		lb. fat		
Below 200	2	268	2·5	2·5
200–19	7	288	2·9	2·6
220–39	6	305	4·0	4·7
240–59	14	309	4·9	5·2
260–79	22	341	4·8	5·8
280–99	31	352	5·3	5·8
300–19	27	358	6·1	6·9
320–39	24	385	5·7	6·5
340–59	11	405	6·4	7·4
360–79	7	413	5·0	6·4
380–99	3	425	7·0	8·3
400–19	2	420	9·0	10·5
420–39	..	..	..	..
440–59	2	482	6·0	7·0
	158			

N.B. In the 'average lifetime production' all two-year and three-year-old records have been corrected to a maturity basis. No animal with only one lactation in the herd has been included in the above table.

animals which had been culled from the herd, and two methods of classification were adopted. In Table 4 the cows are classified as high or low producers according to the *average of the 2- and 3-year-old lactations* (uncorrected for age). All cows culled with only one record of production were naturally excluded, because it is impossible to classify a cow on the basis of one lactation only.

As it might well be argued that some of the low-producing animals at 2 and 3 years of age might later prove to be high producers, the average lifetime production is also quoted in Table 4. Even after leaving the three lowest-producing groups out of consideration (on the grounds that culling for low production would definitely be a factor) it is still obvious that no case exists for suggesting that the high producer breaks down more quickly than the low-producing cow.

Should it be suggested that Table 4 shows only 'normal' lactations, and that the high-producing group might have more abnormal lactations in their lifetime records than the low producer, a column has been added showing the total number of seasons during which the cow remained in the herd. As will be seen, the ratio of 'normal' lactations to season in the herd is relatively constant for each group.

In Table 5 the classification of the cow as a high or low producer has been adopted on the basis of her *lifetime production*, i.e., on the basis of all 'normal' lactations. Even on this classification it will be seen that the high producer still at least holds her own with her low-producing herd mate in number of normal lactations.

TABLE 5. *Analysis of Lifetime Records of all Cows Completing their Herd Life between 1925 and 1938*

Average lifetime production	*No. of cows*	*Average no. of normal lactations*
Below 300	17	3·7
300–19	22	4·5
320–39	29	4·9
340–59	26	5·6
360–79	26	6·4
380–99	17	5·2
400–19	15	6·2
420–39	14	7·0
440–59	4	7·0
460–79	1	8·0
480–99	1	4·0
	172	

N.B. In the 'average lifetime production' all two-year and three-year old records have been corrected to a maturity basis.

No animal with only one lactation in the herd has been included in the above table.

Finally, an analysis was made of the daughters of four bulls which were used in this herd over the same period. Practically all of these daughters have completed lifetime records and, as they were tested in the herd over comparable years, to that extent they were subjected to similar herd conditions. The results, quoted in Table 6, show that the daughters of the best bull stayed in the herd longer than the daughters of the other bulls. Further, it will be seen that the high-producing daughters have not gone out of the herd more quickly than the lower-producing daughters of the same sire.

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TABLE 6. *Comparison of Progeny Results of 4 Bulls used in same Herd over same period (1926–30)*

(*All quoted records are lifetime records*)

Bull letter	*No. of daughters*	*Normal lacts. average no.*	*Production Fat. lb.*		*Number of normal lactations*						
			Dams'	*Daughters'*	*5 and under*	*6*	*7*	*8*	*9*	*10*	*Over 10*
A	16	6·7	390	397	4 394	3 366	2 360	4 430	.. ..	2 398	1 433
B	14	6·2	386	377	7 378	.. ..	2 366	1 331	2 432	1 450	1 371
C	14	5·3	371	345	6 328	2 356	2 376	2 327	2 379	.. ..	.. ..
D	21	4·4	366	326	14 319	1 299	2 348	2 347	2 352	.. ..	.. ..

N.B. The figures above the production-records indicate the number of cows included.

Thus, from this series of analyses into the relation between high production and disease, it is difficult to find evidence that natural high production, as a sole cause, is responsible for any increase in the incidence of disease, or that such high production, of itself, increases a cow's susceptibility to disease. Certainly, the data so far examined may have a limited application, but as the results from several different angles of attack point to the same general conclusion, it would seem reasonable to suggest that either the general observation mentioned at the beginning of this paper is biased by lack of information on the more rapidly culled low producer, or it is based on a correlation between high-producing herds and disease, whereas the determining factor is not high production but conditions associated with management, such as feeding.

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AN INVESTIGATION ON THE ALLEGED TOXICITY OF COD-LIVER OIL FOR PIGS

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THE importance of adding cod-liver oil to the rations of live-stock in order to ensure an adequate intake of vitamins A and D is now well recognized [1]. Cod-liver oil is perhaps the most useful and the cheapest source of vitamins A and D for live-stock. From time to time, however, there have been reports of metabolic disturbances in pigs associated with the feeding of cod-liver oil. The most serious of these are the reports by Vianello [2], Bolle [3], Popp [4], Tiedge [5], Wagener [6], Nicolaus [7], and Hauptman [8]. These authors allege that the feeding of cod-liver oil to pigs gives rise to an acute liver dystrophy which usually proves fatal. The clinical symptoms described are vomiting, sudden refusal of food, lassitude, swaying, depression, spasms, snoring, circulatory disturbances, sudden howling, and rapid death. Less acute cases are characterized by diarrhoea, icterus, stiffness, cessation of growth, and ultimate death. Not all the animals to which the cod-liver oil is fed are affected. Thus, in an experiment carried out by Wagener [6] only 5 out of a total of 28 piglings, 6–8 weeks old, showed the symptoms of toxic liver dystrophy. The onset of symptoms occurs at a variable interval after the cod-liver-oil feeding is commenced, e.g. 4–13 days in Wagener's experiments, and 3–4 weeks in a field investigation reported by Tiedge [5]. There would appear to be a breed variation in susceptibility. Nicolaus [7], in an extensive field investigation in Germany, found a mortality of 29·5 per cent in the pure 'Edelschwein', whereas in cross-bred pigs the mortality was only 7 per cent. Age was also a very important factor, only piglings averaging 17·3 kg. (38 lb.) in weight becoming affected.

At post-mortem the findings are consistent with those of acute toxic liver degeneration. Apart from general findings, such as ascites, gastric mucosal haemorrhage, and kidney degeneration, the most characteristic changes are in the liver. This organ is extensively swollen, and histological examination reveals widespread fatty degeneration and necrosis.

There seems to be a great difference of opinion amongst the continental workers as to the constituent of the cod-liver oil which is responsible for the liver dystrophy. Vianello [2] mentions that the oil used in his experiments contained 24 per cent. free fatty acid, a figure which shows that the oil he was dealing with was badly decomposed. Nicolaus [7], on the other hand, states that the degree of decomposition or contamination of the oil does not play any role in the causation of the disease. Popp [4] and Tiedge [5] dealt with cases arising in pigs fed on cod-liver-oil emulsion, and attribute the toxic effects to its composition and especially to the addition of such emulsifying agents as saponin or other glucosides, whereas Nicolaus [7] states that toxic liver dystrophy does not depend on the nature of the emulsifying agent.

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Another important finding is that symptoms are not related to the amount of oil or emulsion fed. Wagener [6] states that doses of from half a teaspoonful up to 200 gm. will produce the disease, and he concludes that the liver damage cannot be associated with the quality or purity of the cod-liver-oil emulsion fed.

Other toxic effects of cod-liver oil.—Besides toxic liver dystrophy, other harmful effects have been attributed to the feeding of cod-liver oil, notably degeneration of the cardiac musculature, described in the papers by Agduhr. An extensive series of references to this aspect and to retardation of growth will be found in the publication by Bell, Gregory, and Drummond [9]. In their own work these authors found that rats did not show a normal growth-rate on diets containing 15 per cent. of cod-liver oil. No lesions of the heart muscle, arteries, liver, or kidneys were, however, detected in rats fed on the oil at this high level. These authors are of the opinion that the toxic substances in fish-liver oils are neither nitrogenous bases, nor are they products of the early stages of the oxidation of cod-liver oil.

Madsen, McCay, and Maynard [10] have described the production of muscle dystrophy and growth-retardation in guinea-pigs, rabbits, goats, and sheep, which they associate with the feeding of cod-liver oil. In their experiments with sheep and goats, they found that daily intakes of 0·7 gm. of oil per kg. of live-weight caused death, with the characteristic muscle lesions, in animals on pasture within 93 days. A level of 0·35 gm. produced similar results within 226 days, but a level of 0·1 gm. caused no ill effects under the same condition over the period. Calves have been found by Davies and Maynard [11] to be far less susceptible to toxic effects than are sheep and goats.

The cod-liver oil used by the American workers [10, 11] was designated 'animal grade', but there was no suggestion that the toxic effects were due to the quality of the cod-liver oil, as similar effects were produced by a United States Pharmacopoeia oil. It is stated that the injurious factor probably resided primarily in the saponifiable fraction and that no evidence was obtained that the vitamins present in the oil were in any way responsible for the lesions. From these experiments, however, it is clearly evident that the severity of the injury was influenced by certain dietary interrelationships, and it is probable that undetermined factors in the diet also played a part in the causation of the lesions.

Object of the Present Investigation

In view of the increasing importance of cod-liver oil in pig nutrition, and in view of reports from other countries, it was thought desirable to ascertain whether or not any evidence could be obtained of its alleged harmful effects in the causation of toxic liver dystrophy and in the production of muscle dystrophy and growth-retardation in fattening pigs. It is obvious that if such sequelae could be attributed to cod-liver-oil feeding it would be undesirable to include it in the rations of pigs.

The literature already cited shows that considerable confusion exists as to the nature of the toxic factors in cod-liver oil. It has been suggested that badly decomposed oils might contain the highest amounts of these

toxic factors. Therefore, in addition to high-grade oils, low-grade 'rotted liver oils' with a high content of free fatty acid were used in this investigation. It is not suggested that the toxicity is due to that content, but it was assumed that this type of oil would be more likely to contain decomposition products, which might be toxic, in highest amount. Owing to the technical difficulties involved in the chemical detection of these decomposition bodies no analysis for them in the oils was made.

Outline of the Investigation

The investigation was carried out in two separate experiments, in each of which 8 pigs were used, a total of 16.

In Expt. I three different grades of cod-liver oil were fed to each of 2 pigs, whilst 2 pigs received no cod-liver oil. Throughout this experiment the pigs received by individual dosing an amount of oil equivalent to 2 per cent. of the meal ration. This quantity is approximately double the amount of cod-liver oil mixed in some proprietary pig-meals, viz. 1 per cent. or 2½ gallons per ton of meal, but in our experiments it is important to note that the oil was not mixed in with meal but given to each pig individually.

In Expt. II the amount of the oils fed was far in excess of the amount of oil likely to be fed under practical conditions of commercial swine husbandry. Feeding of oil commenced at a level equivalent to 4 per cent. of the ration. After 3 weeks the proportion was increased to 6·25 per cent., and after a further 3 weeks to 8·3 per cent. The actual quantities of oil varied between 60 and 240 c.c. It remained at the latter level for 7 weeks, after which the pigs were slaughtered. Only two grades of cod-liver oil were fed in Expt. II. To a third group of pigs olive oil, B.P., in amounts equivalent to those of cod-liver oil was administered. This was considered necessary in order to ascertain whether growth-retardation might be attributable to the possibly harmful effect of high intake of oil and not specifically to the type of oil fed. A fourth group received no oil.

The actual grouping of the pigs in the two experiments was as follows:

Experiment I:

Group 1: 2 pigs receiving no oil, controls.
„ 2: „ „ high-grade cod-liver oil.
„ 3: „ „ medium- „ „
„ 4: „ „ low- „ „

Experiment II:

Group 5: 2 pigs receiving no oil, controls.
„ 6: „ „ high-grade cod-liver oil.
„ 7: „ „ low- „ „
„ 8: „ „ olive oil, B.P.

The method adopted for individual dosing of the pigs with the oils was to give the oil from a large graduated metal syringe to which was attached about 1 foot of pressure rubber-tubing. The requisite quantity of oil was sucked from the container into the syringe, the rubber-tubing then placed in the mouth of the pig, and the oil slowly injected into the back of the pig's mouth. After a few days no difficulty was experienced

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in getting the pigs to take the oil in this way. Quantities of oil up to 120 c.c. were given once daily, but with higher quantities (240 c.c.) the oil was given twice daily. By this method of individual dosage each pig received its full amount of oil. There was no wastage, since the pigs apparently found the olive oil as well as the two cod-liver oils very palatable, and each pig took its appropriate dose greedily.

Pigs.—The pigs used in this investigation were Large White pedigree animals obtained from the Agricultural Research Council, Field Station, Compton, Berkshire. (The pigs at Compton are raised under controlled conditions and are believed to be disease-free.) Litter mates were used in each of the two experiments, and the pigs were so grouped that there was one castrated male and one female in each group. The pigs in Expt. I were 78 days old at the beginning and 196 days old at the end of the oil-feeding period, when they were slaughtered. The corresponding figures for Expt. II were 98 days and 189 days.

Rations.—From weaning and throughout the experiments the pigs were fed a meal mixture consisting of 30 pts. maize-meal, 30 pts. first-grade weatings, 30 pts. barley-meal, and 10 pts. fish-meal. They were fed twice daily, and just before feeding enough water to make a thick porridge was stirred into the meal.

The actual rationing was done on a live-weight basis, viz. 1 lb. of the meal mixture per 20 lb. live-weight, the amount of meal given being calculated to the nearest $\frac{1}{2}$ lb. Up to a maximum of $6\frac{1}{2}$ lb. of the meal was fed, and this was not exceeded during the later stages of the period of the experiment although the pigs were heavier than 130 lb. The pigs were housed so that there were 2 or 3 pigs to each pen. Feeding was not carried out individually, but from a trough fixed in each pen, the amount of food for each pen being based on the total live-weight of the pigs comprising the pen.

We agree that it may perhaps not have been in accordance with the most modern ideas of pig-feeding to use a ration such as that given above throughout the whole period from weaning until the pigs reached above 200 lb. live-weight. That pigs will grow and fatten satisfactorily on such a ration is, however, shown by the average live-weight gains. The protein equivalent per 100 lb. of the ration is 13·1 and the starch equivalent 67·5. Fibre is low—3·8 per cent.—and the mixture is palatable and readily eaten, provided it is prepared fresh and that freshly ground meals only are used. The total fat in the ration is 3·5 per cent. and the digestible fat 2·7 per cent. In the last stages of Expt. II, when the maximum amount of oil was being given, the total fat rose to 10·4 per cent. and the digestible fat to 9·6 per cent.

Properties of the oils.—The properties of the oils used in these experiments are shown in Table 1.

The high-grade oils were those usually sold for animal feeding by the firm which supplied the oils, and were produced from fresh sea-boiled cod-livers by the most up-to-date methods.

The medium-grade oil was prepared on shore, by steam extraction, from livers not quite fresh. A certain amount of similarly prepared oil is on the market for animal-feeding purposes.

The low-grade oils were produced on shore from stale livers by the 'rotting process'. Such oils are now generally used for technical processes connected with the tanning of leather. Very little of these 'rotted oils' are used for animal feeding in Britain, but we understand that such oils may be employed in some foreign countries. [As a discussion of the methods employed in the production of cod-liver oil is outside the scope of this paper no further reference is made to this aspect. Details will be found in the publications by Drummond and Hilditch [12] and by MacLennan [13].]

The olive oil used conformed to the specifications laid down in the British Pharmacopoeia, 1932.

Appearance and taste of the cod-liver oils.—The high-grade oils at ordinary temperatures were pale yellow liquids with a bland taste and slight smell of fish. The medium-grade oil was a liquid of darker yellow than the high-grade oil. It was somewhat acrid to taste and had a marked fishy odour. The low-grade oils were dark brown and were objectionable to both taste and smell. All oils at lower temperatures showed some precipitation of stearines. In very cold weather the containers were shaken vigorously in order to mix the stearines with the oil as thoroughly as possible.

TABLE 1. *Experiments I and II. Particulars of the Oils used*

	Sample of oil	*Free fatty acid, per cent.*	*Saponification value*	*Iodine value*	*Unsap. matter, per cent.*	*Blue value*
Experiment I	High-grade C.L.O.	0·17	185	165	1·03	16·6
	Medium-grade C.L.O.	0·71	182	149	1·50	18·9
	Low-grade C.L.O.	14·17	186	148	1·47	25·5
Experiment II	High-grade C.L.O.	0·14	185	..	0·89	12·0
	Low-grade C.L.O.	5·21	184	..	1·39	5·5
	Olive oil B.P.	..	190–5	79–88	..	..

C.L.O. = Cod-liver oil. .. = not determined.

It will be seen from Table 1 that the outstanding differences between the high-grade and low-grade oils is in their content of free fatty acid, calculated as oleic acid. (For method of estimation see [14].) The free fatty acid of cod-liver oil is generally accepted as an indication of the care which has been taken in its preparation and storage. High free fatty acid, such as that given for the low-grade oils, is indicative of a deteriorating oil, and one which may contain the products of toxic decomposition, which may be harmful when fed to animals. As a basis for comparison, it may be mentioned that in the standard recently adopted by the British Standards Institution [14], the permissible free fatty acid should not exceed 1 per cent. It must be emphasized that we do not regard high free fatty acid as the toxic factor in cod-liver oil, but merely as an indication of a badly decomposed oil which might possibly contain toxic substances.

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The other figures—saponification value, iodine value, percentage of unsaponifiable matter, and the blue value—shown in Table 1 are a guide to the genuineness or otherwise of cod-liver oil, the most useful and easily ascertained of these constants being the proportion of unsaponifiable matter. For example, Harris [15] found the average value for unsaponifiable matter in 150 samples of cod-liver oil to be 1·07 per cent., and the same author states that in the elasmobranch fishes (shark, dogfish, &c.) the value may exceed 50 per cent.

The values given for the olive oil used in Expt. II are taken from the British Pharmacopoeia.

Results

In Expt. I the period of oil-feeding was 118 days and in Expt. II 91 days, the pigs being respectively 196 and 189 days old when the experiments ended.

At no time during the experiments did any of the pigs show clinical symptoms such as are said to be associated with the toxic liver dystrophy

TABLE 2. *Experiments I and II. Weight Increases during the Period of Oil-feeding*

	Group	*Oil-fed*	*Pig's no.*	*Sex of pig*	*Weight (lb.)*		*Individual daily live-weight gain (lb.)*	*Average daily live-weight gain for the group (lb.)*
					At start of expt.	*At end of expt.*		
Experiment (118 days)	1	Controls	1217	M	41	226	1·57	1·46
			1220	F	45	203	1·34	
	2	High-grade C.L.O.	1218	M	47	245	1·68	1·56
			1221	F	38	208	1·44	
	3	Medium-grade C.L.O.	1219	M	50	247	1·67	1·57
			1222	F	48	220	1·46	
	4	Low-grade C.L.O.	1216	M	47	247	1·69	1·48
			1223	F	43	193	1·27	
Experiment II (91 days)	5	Controls	1426	M	64	232	1·85	1·72
			1433	F	56	201	1·59	
	6	High-grade C.L.O.	1428	M	47	175	1·41	1·44
			1434	F	68	201	1·46	
	7	Low-grade C.L.O.	1425	M	69	211	1·56	1·55
			1431	F	66	206	1·54	
	8	Olive oil B.P.	1427	M	53	199	1·60	1·62
			1432	F	66	215	1·64	

C.L.O. = Cod-liver oil; M = Male; F = Female

described by continental workers [4–10]. Two pigs, Nos. 1221 and 1218, fed on the high-grade cod-liver oil in Expt. I, were affected for 5 days with diarrhoea after 1 week on the oil-feeding. This was not thought, however, to be due to the effects of the oil but to a supply of pig-meal which had been in storage for some time at the Royal Veterinary College. In any case the diarrhoea completely ceased when a fresh meal was substituted.

The pigs were periodically driven along a concrete passage to and from the weighing-machine. Muscular stiffness or abnormality in the

gait, such as might be indicative of muscle dystrophy, was never observed.

Apart from the two pigs mentioned above, and one which suffered from an intermittent cough (No. 1425), the pigs in both experiments remained free from any clinical sign of disease, and appeared throughout the experiments to be in remarkably good condition.

Live-weight gains.—The pigs were weighed at weekly intervals during the experiments. Table 2 gives a summary of the live-weight increases during the period of oil-feeding. In Expt. I there is obviously little difference in the average daily live-weight gains of the control group and the three oil-fed groups. In Expt. II there are at first sight some apparent differences between the various groups, but statistical analysis shows that the differences are not significant.

Post-mortem examination.—At the post-mortem examination carried out immediately after slaughter of the pigs, no gross abnormalities could

TABLE 3. *Experiment II. Weights of Various Organs at Post-mortem Examination*

Pig no.	*Oil-fed*	*Weight of heart (gm.)*	*Weight of liver (gm.)*	*Weight of kidneys (gm.)*	*Hot-carcass weight (kg.)*
1426	Control	307	1,788	284	80
1433	,,	269	1,501	276	71
1428	High-grade C.L.O.	263	1,366	263	60
1434	,, ,,	255	1,700	276	70
1425	Low-grade C.L.O.	253	1,462	262	73
1431	,, ,,	252	1,597	274	72
1427	Olive oil, B.P.	255	1,448	267	68
1432	,, ,,	333	1,640	279	71

C.L.O. = Cod-liver oil

be detected in any of them, except No. 1425 of Group VII, in which there was a chronic pericarditis. This pig had not shown any clinical symptoms of cardiac distress during life but had shown a cough, probably of reflex origin. There was no suggestion that the pericarditis was in any way related to the feeding of cod-liver oil.

The dressed carcasses of the eight pigs comprising Expt. II, together with the hearts, livers, and kidneys, were each weighed separately shortly after slaughter and while still warm. The details of these are given in Table 3. The variations in the weights recorded are considered to fall within the normal range for this species.

Reference should be made to kidney weights, since Callow [16] states that, in pigs fed 1 oz. of cod-liver oil per day till they reached 193 lb. live-weight or more, the kidneys were considerably heavier than those of pigs not receiving cod-liver oil or only receiving 1 oz. per day until 100 lb. live-weight was reached. The results obtained in Expt. II (Table 3), where 60–240 c.c. (2–8 oz.) of cod-liver oil were fed, show that there is no significant difference in the weight of the kidneys of the pigs fed on the amounts of oil when compared with the control pigs.

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Livers.—A careful macroscopic examination of the liver of each pig in the experiment was made immediately after the liver was removed from the abdominal cavity. Pieces of appropriate size were fixed immediately for histological sectioning. No macroscopic lesion of any description was found, and there were no signs of abnormal increase in size, fatty degeneration, or areas of necrosis, such as are described by other authors. The macroscopic findings were confirmed by microscopic examination carried out in the Pathology Department of the Royal Veterinary College, which failed to demonstrate any abnormality in microscopic structure.

These findings, together with the absence of any clinical symptoms of illness or disease during life, show clearly that in our experiments no toxic liver dystrophy was produced.

Abnormal odours in the carcasses.—After killing and dressing, an opportunity was afforded for an examination of the carcasses, while they were still warm, for the presence of abnormal odours, which might be attributable to the feeding of large quantities of cod-liver oil.

In the pigs of Expt. I, no abnormal odours were detected in any part of the carcasses. In Expt. II, however, two competent observers[1] stated that the warm fat of 4 carcasses had an abnormal odour. The actual results of the observations were as follows:

Pig no.	*Oil-fed*	*Odour of warm fat*
1426	Control	Slightly abnormal
1428	High-grade C.L.O.	Abnormal
1434	,, ,,	Slightly abnormal
1431	Low- ,, ,,	,, ,,

The odour of the warm fat of the remaining 4 pigs in Expt. II was reported as normal. From the above it will be noted that one of the pigs (No. 1426) reported as showing an abnormal odour is actually one of the controls. Owing to the difficulties involved in this type of test it is doubtful if much reliance can be placed on these results. It should be emphasized that in any case such odours as have been here reported have no bearing on the feeding of cod-liver oil to pigs under practical conditions, where the amount of cod-liver oil fed is only a small fraction of the amounts fed in these experiments.

Discussion

In the experiments reported in this paper we have been unable to produce the toxic liver dystrophy in pigs described by continental workers. The quantities of oil fed were far in excess of those reported in the continental work, where even the comparatively small amount of cod-liver oil fed under practical conditions is stated to have caused liver dystrophy. In our experiments amounts up to 240 c.c. have been fed over long periods without symptoms arising. Even by the feeding of badly prepared 'rotted' oils, containing as high as 5·21–14·17 per cent. of free fatty acid, we were unable to cause any illness in the pigs.

[1] The observers referred to were Dr. Callow, Low Temperature Research Station, Cambridge, and Mr. Brett, Manager of Messrs. Wall's Bacon Factory, Willesden, London.

In seeking for an explanation of the discrepancy between our results and those of the continental workers we may direct attention to the following possibilities:

1. The cod-liver oils used in our experiments were definitely known to have been obtained from the livers of fish belonging to the genus *Gadus*, i.e. they were genuine cod-liver oils. In the continental work referred to, few of the authors give any chemical analysis of the oils which they used. There may thus be some doubt as to the identity of these oils. The fact that most of the oils were sold in the form of an emulsion affords an opportunity for the adulteration of cod-liver oil with other fish, fish-liver, vegetable, or even mineral oils, which renders detection by ordinary chemical methods very difficult. It is known that such adulterated oils, not in emulsion form, are sometimes sold in Great Britain [17], and the possibility occurs that toxic substances may be present in such oils, which are not ordinarily present in genuine cod-liver oils, however badly these may have been prepared.

It would appear that amongst the German workers there is a difference of opinion as to the significance of emulsion or emulsifying agents in the production of toxic liver dystrophy, but it is doubtful if much importance should be attached to this point.

2. A second possibility is that cod-liver oil may not in fact be the agent responsible for toxic liver dystrophy. This possibility finds some weight in the suggestions of some of the continental workers themselves. For example, Wagener [6] states that there are probably other factors as yet unrecognized which, acting together, bring about the disease. Nicolaus [7] reports the occurrence of toxic liver dystrophy in herds of pigs where cod-liver oil was not fed, and refers to the fact that bad hygiene, temporary shortage of food, and other factors incidental to general management may be the cause. Stang, quoted by Tiedge [5] has failed to produce toxic liver dystrophy by feeding cod-liver oil.

More recently, Capodaglio [18] has reported that the symptoms of toxic liver dystrophy arise from the excessive use of maize in the pig's ration, his suggestion being that deficiencies of the maize in vitamin B, lysine, and tryptophane may be the aetiological factors. In experiments carried out in Great Britain on the vitamin-B requirements of pigs [19, 20, 21], it was found that an excessive amount of maize (approximately 80 per cent.) produced symptoms characterized by diarrhoea anaemia, nervous disturbances, and failure to grow. It was clearly shown in this work that these symptoms could be attributed to deficiency of nicotinic acid in the maize. A somewhat similar condition is reported from Pennsylvania, U.S.A. [22], as occurring under field conditions, and in which nicotinic-acid therapy resulted in the spectacular recovery of affected pigs.

3. A third possibility is age susceptibility. It would appear from the reports of some of the continental workers that young piglets just before or just after weaning are most likely to become affected with toxic liver dystrophy, although in some instances older pigs have also been involved. In the present experiments it was not possible to settle the question of age susceptibility. This point is now under investigation and will form the subject of a separate report.

Whatever the cause of toxic liver dystrophy in pigs, it is clear that the work reported by continental authors by no means proves genuine cod-liver oil to be the actual cause. The results of the present investigation clearly suggest that a search should be made for other aetiological factors.

Another aspect of cod-liver-oil feeding to animals is the retardation of growth which it may cause in some species when fed in excessive amounts. In the two experiments reported here we were unable to obtain evidence that excessive doses of cod-liver oil retarded the growth of the pigs fed on an otherwise normal diet. It will be seen from Table 2 that all pigs in the two experiments made satisfactory daily live-weight gains. The weights recorded at the termination of the experiments, viz. pigs 196 days old gave an average live-weight of 223·5 lb. with a range of 193–247 lb., and pigs 189 days old an average live-weight of 205 lb., range 175–232 lb. These figures compare very favourably with the average figures given by Whetham [23] for the Large White breed. The weight given in her survey for pigs aged 197 days is 200 lb. It would appear, then, that pigs are less susceptible to adverse-growth effects from cod-liver oil than are sheep, goats, rabbits, or mice. This suggestion finds some support in the report of Davis and Maynard [11] that calves are far less susceptible to toxic effects than are sheep and goats. Even with the latter two species, in which the experimental work was carried out using synthetic diets, there is a definite possibility that factors in the diet other than the cod-liver oil were responsible for the muscular dystrophy and growth-retardation which were produced.

Our findings in regard to live-weight increase tend to support those of Crowther and Wright [24], who found that there were no significant differences in growth-rate or in efficiency of food-utilization between pigs fed 1 oz. cod-liver oil per day and those not receiving cod-liver oil. The work recorded here, however, is in no sense comparable with that of the above authors [24], since we purposely used far greater amounts of cod-liver oil than would ever be needed under practical conditions of swine-feeding.

Summary

1. An investigation was carried out with a view to securing information on the alleged toxicity of cod-liver oil for pigs.

2. The feeding of high- and low-grade cod-liver oils to 10 fattening pigs in excessive amounts, varying from 2 to 8·3 per cent. of the ration, failed to produce the toxic liver dystrophy described by continental workers. On the contrary, the pigs remained perfectly healthy throughout the feeding-period.

3. Post-mortem examination of the carcasses of the pigs fed with cod-liver oil confirmed the clinical observations. The livers were both macroscopically and microscopically normal. Kidneys and hearts were also normal in appearance and weight.

4. The 10 pigs fed with cod-liver oil made satisfactory live-weight gains up to the conclusion of the experiments, when they weighed

approximately 200 lb. live-weight or more. There was no suggestion that cod-liver oil caused any retardation in growth-rate.

5. Two pigs given equivalent amounts of olive oil and 4 control pigs not receiving any oil made similar live-weight gains.

6. There were no significant differences in the final weights recorded between groups of pigs receiving high-grade cod-liver oil containing approximately 0·15 per cent. free fatty acid and groups receiving medium- or low-grade 'rotted' oils containing up to 14·17 per cent. free fatty acid. Neither was there any significant difference between the final weights of the oil-fed pigs and the control pigs.

7. It is concluded that, provided a cod-liver oil is known to be genuine, it is not a factor in the causation of toxic liver dystrophy, even when given in excessive amounts. Suggestions are made regarding other possible aetiological factors, in particular a deficiency of nicotinic acid in the diet.

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THE STANDARD ERRORS OF FIELD PLOTS AT ROTHAMSTED AND OUTSIDE CENTRES

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SINCE replicated experiments of modern design were introduced at Rothamsted in 1925 nearly 1,200 analyses of various measurements arising from these have been carried out and the results put on record in the annual reports of the Station. One of the figures tabulated has been the standard error of a single plot yield. This value is given in the actual units of measurements and also expressed as a percentage of the mean yield of all plots in the experiment. The first figure taken in relation to the design and degree of replication gives a measure of the quantity of produce that the experiment can reveal as a significant difference between treatments; the second affords a ready comparison of the precision of experiments having the same size and structure. In the course of a series of field experiments on any particular crop the experimenter begins to recognize an average value around which his standard errors group themselves, and notes an experiment as accurate or variable according to the departure of its standard error from this normal value. In the following paper the standard errors per plot have been collected from all experiments carried out at Rothamsted, Woburn, and the outside centres over the fourteen seasons 1925–38. They are grouped by crops, and further classified according to plot-size and experimental design, in order to bring out the values that have been obtained under a wide range of agricultural conditions in England.

The standard error is derived from the residual variance after the effects due to the experimental treatments applied and to fertility differences between blocks—or rows and columns in Latin squares—have been removed. Its chief component is soil heterogeneity within blocks or within rows and columns, but the incidence of plant disease due to insect or fungus pests, and the depredations of birds and vermin often contribute largely to it. Where small numbers of individuals are concerned as in micro-plots or with certain horticultural crops, genetical differences between the plants play an important part. The effect of working errors in the field, such as errors of estimation of areas and weights is probably only a minor element in the final result, provided that no gross mistakes have been committed. Something can be done by close observation in the field to minimize the effects of soil variation, firstly by choosing a site that is known to have carried a uniform crop in the previous season, and secondly by arranging blocks or rows and columns to take out as much variation as possible. The Latin-square arrangement is highly effective in dealing with variation that runs through the experimental area in strips, a state of affairs frequently encountered in practice. Examination of the subsoil and, where crops sensitive to soil acidity are concerned, rapid determinations of soil reaction also help greatly in avoiding the worst effects of soil variation. In

the experiments reported it may be assumed that the ordinary precautions have generally been taken, and working errors have been reduced to a minimum.

Figures derived from very poor crops are excluded from the tables. Usually experiments that fail are not harvested; but a few that were practically failures, but for various reasons were weighed and reported, have been omitted from discussion. Only 14 experiments, or less than 2 per cent. of the total, had to be rejected on grounds of low yield. The standard errors for these rejected experiments were considerably above the average for trials giving normal yields.[1]

Crops and measurements.—All the common farm crops are represented in the data. Potatoes with 188 experiments are the biggest individual group. The largest number of experiments has been conducted on sugar-beet. In the earlier years, however, statistical analysis was carried out on the yield of roots (153 experiments), and in the later years total sugar was determined (133 experiments). There are 232 results from sugar-beet tops, though this number does not represent the total number of experiments, since in a number of trials the tops were not recorded. Swedes and mangolds have been the subject of a much smaller number of trials. For the root crops the measurements have been weight of roots and tops, and frequently plant-number also. The percentage of ware in potatoes, and of sugar and purity of juice in sugar-beet have usually been determined. The yield of green stuff has been obtained for a number of crops of kale. Meadow hay has been fairly extensively studied, but seeds hay and clover hay comparatively little. Cereals have yielded a large number of values both for grain and for straw.

In 1933 the modern replicated designs were applied to vegetable crops, many experiments on Brussels sprouts, cabbages, and early potatoes being on record, but the data relating to carrots, onions, and the various vegetable legumes are still scanty. Certain of the experiments with vegetable crops provide figures relating to some aspect of quality of the produce in addition to the gross yield.

Size of plots.—In uniformity trials the size of the individual plots has been shown to influence the magnitude of the standard error [1]. When sufficient values were available the data have been grouped into three categories according to plot-area. The first comprises all plots of 1/100 acre and over; these may be regarded as full-sized field plots, most of them falling between 1/40 and 1/60 acre. The second group contains plots below 1/100 acre but not less than 1/200 acre; these are very small plots for ordinary purposes but are bigger than genuine micro-

[1] The values obtained were:

Crop	*No. of experiments*	*Yields less than*	*Standard error per cent.*
Potatoes	3	3 tons/acre	15·6
Sugar-beet	4	4 tons/acre	16·8
Barley	1	6 cwt./acre	14·7
Lucerne	1	6 cwt./acre	32·7
Kale	5	5 tons/acre	29·3

plots. The third group contains microplots proper with a size below 1/200 acre.

Design of experiments.—Certain designs have been found to be more effective than others in eliminating the effects of soil heterogeneity. Thus Latin squares have on the whole been more precise than randomized blocks [2]. In grouping the data Latin squares have therefore been separated from randomized blocks.

Experimental Farms compared with Commercial Farms

In Table 1 the percentage standard errors per plot for various groups of crops are set out for Rothamsted and Woburn against the outside centres, where replicated experiments have been conducted on commercial farms either by the Rothamsted staff or by local workers. Latin squares are separated from randomized blocks. Mangolds and swedes have been grouped, all cereals have been assembled, and all types of hay have been taken together. The mean values of the standard errors in units per acre are also given.

TABLE 1. *Standard Errors: Rothamsted (R), Woburn (W), and Outside Centres (O), 1925–38*

Crop	*Latin squares*				*Randomized blocks*				*Actual value per acre*	
	R.W.		*O*		*R.W.*		*O*			
	No.	*Per cent.*	*No.*	*Per cent.*	*No.*	*Per cent.*	*No.*	*Per cent.*	*No.*	*Mean of all per acre*
Potatoes	7	4·6	93	7·7	17	9·3	71	10·7	188	0·76 tons
Sugar-beet: roots	9	7·2	56	5·8	16	8·8	72	8·9	153	0·85 tons
,, total sugar	..	..	17	6·8	8	9·1	108	10·6	133	3·38 cwt.
,, tops	9	7·3	60	8·4	24	11·7	83	12·2	176	1·04 tons
Mangolds and swedes: roots	1	3·3	22	7·8	11	9·3	9	12·5	43	1·73 tons
,, tops	1	5·2	11	9·9	5	11·2	4	10·9	21	0·52 tons
Kale	6	7·2	5	7·8	11	8·6	11	8·0	33	1·39 tons
Cereals: grain	13	8·3	17	8·7	44	11·3	5	14·0	79	2·07 cwt.
,, straw	13	8·6	16	9·4	35	9·7	3	13·4	67	3·05 cwt.
Hay	..	..	23	9·2	3	11·1	27	10·8	53	3·90 cwt.

The percentage standard errors for the common field crops tend to be smaller in Latin squares than in randomized blocks, and smaller at the main experimental stations than at the outside centres. Thus, neglecting the classes having less than seven values, Latin squares at Rothamsted and Woburn range from 4·6 to 8·6 per cent., Latin squares at outside centres 5·8 to 9·9 per cent., randomized blocks at Rothamsted 8·6 to 11·7 per cent., and randomized blocks at outside centres 8·0 to 14·0 per cent.

In consequence of the more complex experiments at Rothamsted and Woburn, the block-size at these stations was in general larger than at the outside centres. Thus the blocks in the sugar-beet experiments at the experimental stations contained an average of 12 plots, but those at the outside centres contained an average of only 8 plots. Since larger blocks eliminate less variance due to soil fertility than do smaller blocks, the standard errors of experiments with large blocks would be expected to be

greater than the standard errors of those with small blocks; hence what might be termed the working precision is higher at the experimental stations than would appear from the figures in Table 1. The better results at the experimental stations may be explained by the special care taken in the choice of sites, and the continued supervision and skilled workmanship by a special field staff. On the other hand, the somewhat lower precision attained at commercial farms is not a serious objection to this type of experimentation, in fact experience has shown that the precision attained is sufficient to bring out with statistical significance most of the effects under examination, with the additional advantage that the data cover a wide range of soil and climatic conditions. The experimental stations are specially suited for carrying out trials of great complexity, especially rotation and other long-term experiments, and for investigating the finer points of soil management; the outside centres for increasing the breadth of the survey of the larger and more important effects.

The mean standard errors of the field crops when expressed as percentages are remarkably uniform; thus within one class, for example randomized blocks at the experimental stations, they lie between 8·6 and 11·7 per cent., and the ranges of standard errors within the other classes are of similar order.

With sugar-beet there is a considerable difference between the standard errors for roots and tops. The figures for tops in Table 1 are derived only from experiments in which the area of tops harvested was the same as that of roots. The differences, therefore, which are as high as 3·3 per cent., cannot be ascribed to smaller plot-area. This lower precision for tops may possibly be explained by the fact that at the time of lifting, the tops are past their maximum development and are in varying stages of deterioration and wilting. Moreover, the manner and time of exposure of the tops in the interval between topping and weighing off will further increase the variability. It is difficult to attain uniformity in these operations in practice, and this probably accounts for part of the variability shown by the weights of the tops.

The roots and tops of mangolds and swedes show similar though perhaps less pronounced differences in standard errors, with the exception of the sub-group randomized blocks at outside centres where the standard error for tops (on only four observations) is less than that for roots.

The cereals show much the same values for grain and straw.

Quality Measurements

In addition to the yield determinations, subsidiary measurements have been made on various crops in a number of experiments. Since the riddle regulations of the Potato Marketing Board were introduced the percentage of ware in the potato crops has been determined. The sugar-content of sugar-beet roots and often the purity of the juice have also been measured. Plant-counts are usually taken in beet experiments. The available data are collected in Table 2.

The following discussion, and Table 3, refer only to experiments providing data relating to both yield and quality measurements.

TABLE 2. *Quality and other Measurements*

Standard errors, per cent. and actual

	Rothamsted and Woburn			*Outside and other centres*			*Total*		
	No.	*Per cent.*	*Actual*	*No.*	*Per cent.*	*Actual*	*No.*	*Per cent.*	*Actual*
Potatoes:									
Percentage ware . .	6	6·4	5·35	45	4·8	3·64	51	5·0	3·84
Sugar-beet:									
Percentage sugar . .	20	2·3	0·41	137	2·4	0·41	157	2·4	0·41
Percentage purity . .	..	..	..	58	1·4	1·07	58	1·4	1·07
Plant-number × 1000 .	8	4·4	1·25	60	6·8	1·79	68	6·5	1·78

It appears that the variability of the quality measurements is distinctly lower than that of the corresponding yields. The values for percentage ware of potatoes are actually determined by a sampling procedure, but even so their variability is comparatively low.

TABLE 3. *Yield and Quality Measurements*

Standard errors per cent.

Crop	*No. of expts.*	*Yield of roots*	*Total sugar*	*Ware per cent.*	*Sugar per cent.*	*Plant-number*
Potatoes	51	10·6	..	5·0	..	..
Beet	128	7·7	..	..	2·4	..
,,	29	..	12·1	..	2·4	..
,,	37	7·3	..	..	..	5·5
,,	31	..	12·2	..	..	7·7

The laboratory determinations show still more markedly that the quality of sugar-beet is much less variable than the yield, the mean standard error for sugar being 2·4 per cent. whilst that for roots is 7·7 per cent. Probably the attacks of vermin, disease, and the effects of soil heterogeneity have very much less effect on sugar-content and purity of juice than they have on yield per acre. Sugar-content is a relatively accurate determination, and effects of fertilizer treatment upon it have repeatedly been demonstrated with statistical certainty in spite of their actual magnitude being exceedingly small.

As regards plant-number, comparatively small differences in soil fertility will be enough to influence yield, but may be quite insufficient to kill off the plants entirely and thus fail to affect the population. When plant-number is unaffected by the experimental treatment and is significantly related to yield, the standard errors for yield may be adjusted for plant-number with advantage. Thus in the 14 experiments on sugar-beet in 1938, with the most variable plant population the mean standard error for sugar per acre unadjusted was 14·1 per cent. Adjustment for plant-numbers reduced this to 11·1 per cent.

Effect of Experimental Design and Plot-size.—In Tables 4 to 9 the data for those crops providing fairly large numbers of observations have been classified according to experimental design and when possible by plot-size.

Main-crop potatoes.—The figures for 188 experiments on main-crop potatoes are given in Table 4. The classes with the greatest number of experiments compare Latin squares and randomized blocks on full-sized

TABLE 4. *Main-crop Potatoes: Total Produce*

Standard errors per plot, actual in tons per acre and percentage. (Figures in brackets are the number of experiments.)

System of Replication	*Plot-size in acres*		
	1/100 and over	*1/101 to 1/200*	*Below 1/200*
Latin squares:	(55)	(25)	(20)
Per cent.	6·2	8·3	9·9
Tons	0·59	0·63	0·91
Randomized blocks:	(76)	(7)	(5)
Per cent.	10·3	8·8	16·7
Tons	0·86	0·91	1·13

plots. The standard errors per plot are 6·2 and 10·3 per cent. respectively, and thus fall in the order that has already been demonstrated by other studies [2].

Differences in the same direction occur in the other two pairs of classes, though these differences are irregular owing to the varying numbers of observations in the classes.

The effect of plot-size on precision is shown in the three groups of Latin squares, each of which contains a fair number of experiments, the values being 6·2 per cent. for full-sized plots, 8·3 per cent. for small plots, and 9·9 per cent. for microplots.

The general mean for all potato experiments is 8·9 per cent., or 0·76 tons per acre of total produce.

Sugar-beet.—Up to and including 1935 the data for washed roots were analysed, but from 1936 onwards the figures for total sugar were analysed instead. Hence there are practically no experiments in which both quantities were statistically analysed, so that no direct comparisons can be made between their standard errors.

Table 1 indicates that in each of its sub-classes the standard errors for total sugar are slightly higher than those for roots. Without direct comparisons it is difficult to say how far these differences are due to variation between years, or how far they are due to the fact that the figures for total sugar contain not only the errors involved in the determination of clean roots, but also those arising out of the estimation of sugar percentage.

For the purpose of Table 5 the percentage standard errors of roots and total sugar have been combined to form one series covering all years.

As with potatoes the groups with the largest numbers of observations give the comparison of the two systems of replication on full-sized plots. Latin squares gave a mean standard error per plot of 5·9 per cent., whilst randomized blocks gave a standard error of 9·8 per cent. A difference in the same direction, though smaller, was obtained on the plots of area less than 1/100 acre.

In the randomized blocks the smaller plot-size did not apparently

TABLE 5. *Sugar-Beet: Roots and Total Sugar*

Standard errors per cent. per plot

System of replication	*Plot-size in acres*	
	1/100 and over	*Under 1/100*
Latin squares:	(75)	(7)
Per cent. . . .	5·9	8·4
Randomized blocks:	(183)	(21)
Per cent. . . .	9·8	10·0

result in any appreciable increase of the standard error. In the Latin squares, the mean standard error for the smaller plots, though less well determined with only 7 observations, was 2·5 per cent. greater than that for the full-sized plots.

The general mean for the 286 experiments in this table was 8·8 per cent.

TABLE 6. *Sugar-beet: Tops*

Standard errors per plot, actual in tons per acre and percentage

System of replication	*Plot-size in acres*	
	1/100 and over	*Under 1/100*
Latin squares:	(65)	(4)
Per cent. . . .	8·2	9·4
Tons	0·83	1·04
Randomized blocks:	(91)	(16)
Per cent. . . .	12·0	12·4
Tons	1·16	1·19

In Table 6 only those standard errors for tops are included where the area harvested was the same for tops as for roots.

On the full-sized plots the standard error per plot for Latin squares at 8·2 per cent. was again considerably lower than that for randomized blocks at 12·0 per cent. On the smaller plots the difference was also appreciable. The differences of standard errors between large and small plots were not large, though in both systems of replication the larger standard error occurred on the smaller plots.

In addition to the above 176 experiments, there were 56 others in which the tops were harvested and recorded from one-half to one-quarter or even less of the plot area. In general this smaller area was chosen by taking a certain number of rows along the middle of the plot and not by taking a random selection of a number of rows from the whole plot.

Though the smaller area of tops in these cases would be expected to result in a somewhat larger standard error, the method adopted of selecting the area would result in a much wider variation than if rows were randomly selected within the plots, or if these smaller areas were contiguous.

This wider variation is well illustrated by the standard error of 15·6 per cent. for 17 experiments on large randomized blocks, compared with 12·0 per cent. above, and 15·8 per cent. for 36 experiments on small

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randomized blocks, compared with 12·4 per cent. above. The three experiments on Latin squares also gave larger standard errors compared with those above in Table 6.

Kale, Swedes, Mangolds.—These root crops have been much less extensively investigated than potatoes and sugar-beet. There have been 33 experiments on kale, 22 on mangolds, and 21 on swedes. In these circumstances the division of the results according to plot-size and design need not be set out in full. The overall comparison of Latin squares and randomized blocks is as follows:

TABLE 7. *Kale, Swedes, Mangolds*

Standard errors per plot per cent.

	Latin squares		*Randomized blocks*	
Kale	(11)	7·5	(22)	8·3
Mangolds: roots	(7)	5·5	(15)	11·1
tops	(3)	4·2	(7)	11·7
Swedes: roots	(16)	8·4	(5)	9·7
tops	(9)	11·2	(2)	9·0

With the exception of the tops of swedes, for which only two experiments are recorded, the mean values for Latin squares are always smaller than those for randomized blocks.

Grain crops.—Barley and wheat provide most of the observations in this section, only a very few on oats are included. Since there seemed to be no appreciable differences between the standard errors of these three crops they have been grouped together here. The values given in Table 8 are divided according to the method of harvesting adopted. Usually the whole produce of each plot was harvested and threshed separately, but in a number of experiments on commercial farms this proved to be impracticable, and small random samples were taken from each plot for small-scale threshing at the experimental station. By this method only a small fraction of the produce from each plot was actually weighed.

TABLE 8. *All Cereals*

Standard errors per plot, actual in cwt. per acre and percentage

	Grain		*Straw*	
	Fully harvested	*Sampled*	*Fully harvested*	*Sampled*
Latin squares:	(13)	(17)	(12)	(17)
Per cent.	7·2	9·5	7·0	10·4
Cwt.	1·64	2·20	2·33	2·98
Randomized blocks:	(46)	(3)	(36)	(2)
Per cent.	11·3	16·8	10·0	11·2
Cwt.	2·16	1·95	3·41	1·60

There are no consistent differences between the standard errors for grain and straw. Latin squares once again show considerably lower standard errors than randomized blocks. The fully harvested plots show

smaller standard errors than those that are sampled. This matter was fully investigated by Yates and Zacopanay [3], who found that the average loss of information in 16 experiments was 31 per cent. The standard errors in the above table indicate a similar loss of information.

Meadow and Seeds Hay.—The errors obtained in 46 experiments on meadow hay are collected in Table 9.

TABLE 9. *Meadow Hay*

Standard errors per plot, actual in cwt. per acre and percentage

	Size of plot in acres		
	1/100 and over	*1/101–1/200*	*Under 1/200*
Latin squares:	(16)	(5)	..
Per cent.	9·6	9·0	..
Cwt.	3·18	4·14	..
Randomized blocks:	(10)	(8)	(7)
Per cent.	9·4	11·9	12·2
Cwt.	2·68	5·80	5·54

So far as the available information for meadow hay goes, the difference between the accuracy of Latin squares and randomized blocks shows up less than usual. Owing to the relative absence of cultivations the strip effects would probably be less marked on old grass than on arable land, so that some of the special advantages of the Latin-square design would not appear. In the randomized blocks the errors show some indications of increasing as the plot-size is reduced.

There have been only seven experiments on seeds hay, giving a mean standard error of 8·9 per cent., or 3·30 cwt. per acre.

For both meadow and seeds hay, the percentage standard errors for dry matter are considerably lower than those for hay as weighed in the field, although there are few experiments bearing on this point:

Meadow hay, field weights	(46)	10·3%	3·99	cwt. per acre
Meadow hay, dry matter	(6)	7·4%	2·10	,, ,,
Seeds hay, field weights	(7)	8·9%	3·30	,, ,,
Seeds hay, dry matter	(2)	6·9%	2·44	,, ,,

The amount of moisture contained in hay as weighed in the field depends on the extent to which the various small lots had been 'made' at the time of weighing, and in catchy weather considerable differences may occur from plot to plot.

Market-garden crops.—The standard errors of the comparatively few trials so far conducted on vegetable crops are collected in Table 10. The data are not extensive enough to permit of subdivision; almost all the experiments were carried out on commercial farms.

These values are not well determined and refer to full-sized and to small plots, but so far as they go they suggest that the market-garden crops are if anything somewhat more variable than the field crops. The greater degree of cross-cropping that occurs on market-garden land may account for part of this, but more discrimination is usually practised in harvesting vegetable crops than is customary with farm crops, and some of the

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produce actually grown may be rejected as unfit for use, thus introducing additional variation.

The difference in precision between early potatoes at 14·3 per cent. and main crops at 10·7 per cent. on randomized blocks at outside centres is

TABLE 10. *Market-Garden Crops*

Standard errors per cent. and per acre
Mean of all designs and plot-sizes

	No. of expts.	*Standard error*	
		Per cent.	*Per acre*
Brussels sprouts	16	10·7	4·24 cwt.
Early potatoes	13	14·3	0·54 tons
Cabbages	8	10·9	1·25 ,,
Onions	6	13·2	1·05 ,,
Green peas	6	10·2	4·87 cwt.
Green beans (French and Runners)	5	15·3	7·26 ,,
Beetroot	5	13·7	1·09 tons
Carrots	3	8·6	1·08 ,,

striking. The growing of earlies in disease-infested land may contribute to this result, but early lifting in itself serves to record those marked variations in the first development of a crop that would probably be largely smoothed out at maturity.

The values for sprouts and green beans refer to the totals of many successive pickings. The standard errors for the individual pickings are usually very much higher than the tabulated values.

Distribution of Standard Errors

The distribution of the standard errors according to size-groups has been taken out for some of the larger classes of data. The figures are given in Table 11.

TABLE 11. *Distribution of Standard Errors by Size-Groups*

Standard error per cent.	*Sugar-beet*						*Potatoes Total produce*	
	Roots		*Total sugar*		*Tops*			
	Latin squares	*Random. blocks*	*Latin squares*	*Random. blocks*	*Latin squares*	*Random. blocks*	*Latin squares*	*Random. blocks*
0–4	22	7	3	3	7	1	15	2
4·1–8	27	36	9	41	29	23	55	31
8·1–12	13	28	4	41	22	40	18	26
12·1–16	2	12	1	19	7	26	7	21
16·1–20	1	4	..	6	3	8	4	3
20·1–24	..	1	..	3	1	5	1	4
24·1–28	..	..	..	2	..	3	..	1
Over 28	..	..	..	1	..	1	..	..
Total	65	88	17	116	69	107	100	88

The distributions for Latin squares are more compact than those for randomized blocks. It is by no means rare to find Latin squares with

standard errors of less than 4 per cent., but with randomized blocks values as low as this are quite exceptional. Similarly with Latin squares, there are few values exceeding 20 per cent., but the randomized blocks show more of these extreme values.

Main and Split Plots

A common design in field experimentation involves the splitting of the main treatments into one or more subtreatments. Separate standard errors are computed for the main plots and the sub-plots. In Table 12 the standard errors per plot are collected for the main plots and the corresponding sub-plots in a series of experiments.

TABLE 12. *Comparison of Main and Split Plots*

	Standard errors per cent.		
	No. of expts.	*Main*	*Split*
Wheat grain	7	11·5	10·9
,, straw	7	9·3	9·4
Barley grain	11	7·2	12·1
,, straw	11	7·8	13·2
Sugar-beet roots	9	11·9	15·4
,, tops	13	7·4	10·3
,, total sugar	4	6·5	10·6
Potatoes	17	7·8	7·8

Considerably higher standard errors for split plots are shown for barley grain and straw, and for roots, tops, and total sugar of sugar-beet.

For potatoes, wheat grain and straw, main and sub-plots show practically the same standard errors. Although in general the standard error on the sub-plots is somewhat larger than on the main plots, the accuracy of the sub-plot comparisons is usually greater than that attained in main-plot comparisons, owing to the higher degree of replication.

Conclusions

The standard errors per plot obtained in some 1,200 analyses relating to data from modern replicated experiments carried out at Rothamsted, Woburn, and outside centres during 1925–38 are recorded and classified. Latin squares gave considerably lower standard errors than randomized blocks. The standard errors of sub-plots tended to be larger than those of main plots of which they were the components, but this is more than offset by the higher replication on the sub-plot comparison. Market-garden crops usually gave rather higher standard errors than ordinary farm crops. The standard errors for quality determinations such as sugar percentage in beet and tuber-size in potatoes were as a rule distinctly less than the corresponding figures for yield.

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